# The developmental interrelations of action representations in early childhood

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## Zusammenfassung

Im Laufe der Kindheit entdecken Kinder jeden Tag neue Ereignisse, erwerben neue Handlungskompetenzen und tauschen sich mit Sprache über diese Geschehnisse aus. Die hier vorliegende Dissertation untersucht, wie die Repräsentation von Handlungsproduktion, Handlungswahrnehmung und Handlungssprache zusammenhängen. In drei Studien wurde über unterschiedliche Altersgruppen erkundet, wie die Repräsentationen miteinander kommunizieren und wie die Kommunikation über die Entwicklung in den ersten drei Lebensjahren verläuft. In Studie I wurden die Trajektorien von Handlungswahrnehmung und Handlungsproduktion bei Kindern zwischen 12 und 30 Monaten erforscht. Ergebnisse zeigten einen Vorsprung der Handlungswahrnehmung bei bekannten Handlungen und eine parallele Entwicklung bei unbekannten Handlungen. Nach erworbener Handlungskompetenz wirkt sich die Handlungsproduktion differenzierend auf die Handlungswahrnehmung aus. In Studie II wurde die Kommunikation zwischen Handlungssprache und Handlungswahrnehmung bei Kindern zwischen 12 und 24 Monaten erforscht. Ergebnisse fanden einen interferierenden Einfluss der Handlungssprache auf die Handlungswahrnehmung im Alter von 12 Monaten und einen faszilitierenden Einfluss im Alter von 24 Monaten. Diese Ergebnisse waren jedoch auf solche Verben beschränkt, die schon im produktiven Sprachrepertoire der Kinder vorhanden waren. Studie III erforschte die Notwendigkeit von Handlungsproduktion für das Erlernen von Handlungssprache bei Kindern zwischen 24 und 36 Monaten. Ergebnisse zeigen einen faszilitierenden Einfluss von Handlungsproduktion auf das Erlernen von Handlungssprache im Fenster zwischen 24 und 30 Monaten. Zusammengenommen zeigen die Befunde vielfältige Beziehungen zwischen den Repräsentationen von Handlungsproduktion, Handlungswahrnehmung und Handlungssprache, deren Stärke sich über die Entwicklung verändert.

## Abstract

During their first years of life, children explore events, develop new action competences and use language to talk about these happenings. The current dissertation explored the interrelations between action production, action perception and action language. In three studies, I investigated how the representations were interrelated and how the trajectories of the interrelations developed over the first three years of life. In Study I, the trajectories of action perception and action production in children between 12 and 30 months were analyzed. Results revealed an advance of action perception in familiar actions and a parallel development in novel actions. After the acquisition of action competence, this then leads to a differentiation in action perception. Study II explored the communication between action language and action perception in children between 12 and 24 months. Results showed an interfering influence of action language on action perception at the age of 12 months and a facilitating influence at the age of 24 months. These results were limited on those verbs, that were already in the productive repertoire of the children. Study III investigated the necessity of action production for the acquisition of action language in children between 24 and 36 months. Results revealed a facilitatory influence of action production on action language between 24 and 30 months. Taken together, the evidence speaks for diverse interrelations between action production, action perception and action language with changing priorities over the course of development.

**Inhalt**

## Danksagung

Dem Ende einer Promotion geht eine langwierige und mit vielen Aufgaben gestreute Zeit voraus. Aber eine Promotion wäre nicht allein durch stetiges Arbeiten möglich, sie erfordert die Zusammenarbeit, Hilfe und Unterstützung von vielen anderen Menschen. Diesen Menschen soll an dieser Stelle gedankt werden.

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# PART I

# Preface

Imagine Alina, a young girl of 24 months of age, sitting in the kitchen high chair and observing her mother making stewed apples. Her mother is telling that she is going to boil the chopped apples with a bit of sugar before the compote is ready for eating. What does Alina understand when her mother talks of eating? Is she associating the act of putting things into the mouth and chewing them? By 24 months of time surely. But what does this association involve? Does she imagine herself eating the stewed apples? Probably. Does she imagine her father or mother eating apples? Probably. What about if her mother continues her dialog with Alina and tells that her father will be back shortly and he is going to hammer a nail for the new pink mirror for her into the wall. Is she associating the act of using a hammer to manipulate nails? By 24 months of age not surely. But if so, what does this association involve? Does she imagine herself hammering nails? Probably not. Does she imagine her father or mother hammering? Probably only her father. Does she need to have own hammering experience in order to associate anything at all with this word?

Lets now imagine time has passed and the stewed apples are cooled off. Alina observes her mother eating the first bits with the spoon and shortly after begins to eat herself. Does she understand the act of eating when observing her mother? Surely. But does the way she observed the eating interacts with her own eating? Maybe. Is it necessary to understand her mother before she herself can start eating? Maybe. Does her eating experience changes the observation of her mother? Maybe. The door opens and her father comes in. She jumps for joy and pulls her father into her room in order to hang the mirror. Her father gets the nail and hammers it into the wall. Does she understand the act of hammering when observing her father? Maybe. But does the way she observed the hammering interacts with her own hammering? Maybe, if she did it before. Does her hammering experience changes the observation of her father? Maybe.

Quite a normal situation for a 2-year-old child at her home. Alina observes her parents, she is doing things together with her parents and she hears lots of spoken languages and already started speaking herself. Every-day life is quite busy. Children are thus confronted with many different persons and observe them acting and communicating about things of major and minor importance. And while adults are in mostly all situations able to understand and answer the requests made by our counterparts, children in the early years need to develop their understanding of how this can be done.

# 1 Theoretical Framework

Most activities in childhood and later on share the involvement of actions: children perform actions (action production), children observe other's actions (action perception) and children produce and perceive language related to actions (action language). But this concerns only the one-dimensional perspective. Every-day life is much more complex: In addition, children perform actions they have perceived, they perceive actions they have produced, they talk about perceived and produced actions, they produce actions they or someone else talked about and they perceive actions they or someone else talked about. These very interrelations between action production, action perception and action language in early development are the focus of the present dissertation. The key questions are: Do action production, action perception and action language interact in development? If so, how do they interact with each other? And, what are the developmental trajectories of the interrelations between 12 and 36 months of age?

## 1.1 Representations

The way action production, action perception and action language might "talk to each other" is on the level of representations (Barsalou, 2008; Prinz, 1997). Representations can be thought of in terms of "how past experience is coded and processed so that it may indeed be relevant and usable in the present when needed" (Bruner, 1964, p. 2). The end product of such a coding and processing system is then called a representation. This conception of representations is similar to Gallistel (1989; 1990) who defines a representation as an interrelation of the environment and processes in the brain that adapt the organism onto this environment. Both conceptions are rather difficult to handle when investigating developmental questions. Palmer uses a more pragmatic definition: "The nature of the representation is that there exists a correspondence (mapping) from objects in the represented world to objects in the representing world such that at least some relations in the represented world are structurally preserved in the representing world" (Palmer, 1978, p. 266). After having defined representations in a way that it can be used for infants and children, the question is which types of representations an infant or a child can form.

## 1.2 Modes of representations

Bruner (1964) further differentiates between three modes of representations: enactive, iconic and symbolic representations. The enactive mode of representation refers to all experience stored in terms of motor response, the iconic mode of representation refers to all events in perception of images and the symbolic mode of representation refers to information stored in arbitrary symbols like language. Previous research mostly concentrated on the differentiation between the enactive and symbolic representations and one issue of central interest in the differentiation debate is how developmental changes in the modes of representations work. Bruner states a clear temporal order with enactive representations being the first one, iconic representations being the second one and symbolic representations being the last one. “Their appearance in the life of the child is in that order, each depending on the previous one for its development, yet all of them remaining [...] intact through life” (Bruner, 1964, p. 2). This statement on the development of the different representations has been called the “representational development hypothesis” by Kosslyn (1978) and was favored by other researchers as well (Piaget & Inhelder, 1966; Werner, 1926). Although Bruner (1964) and Kosslyn (1978) describe that the three modes develop one after another not much is said about whether and how the modes of representation interact early in life, that is how the functional relationship between the different representations looks like.

## 1.3 Development of the modes of representations

Two different views of the development of the modes are contrasted in the following paragraphs.

According to Piaget (1951, 1967), children begin in a sensorimotor stage (0 - 2 years) which is then followed by the preoperational stage (2-7 years). In the sensorimotor stage children coordinate their representations in perception and motor action. The child constructs an understanding of the world by acting on the world (assimilation) and adjusting these actions by feedback from the world (accomodation). In the preoperational stage then, children start developing symbolic representations of language. As language production starts already in the substages V and VI of the prior sensorimotor stage, he believed the early words to be of sensorimotor schemata character. These sensorimotor schemata are transformed into symbolic ones at a later level. The Piagetian view of the functional relationship thus assumes a functional transformation of enactive representations into symbolic representations (for a similar view, see: Vygotsky, 1987).

According to Mandler (1988), children develop perceptual representations (enactive representations in Bruner's term) and conceptual representations (symbolic representations in Bruner's term). She acknowledges achievements in the perceptual domain similar to Piaget, but she believes conceptual representations to be of special importance for language acquisition. Information in the conceptual system must be different from information in the perceptual system. Both modes of representation are thus assumed to develop simultaneously and in parallel. Thus, and in contrast to Piaget, the representations do not derive from each other. Information in the conceptual system is generated through perceptual analyses, that is trough comparison of perceptual similarities. This perceptual analysis is therefore independent of the history in sensorimotor functioning. Mandler's view on the functional relationship thus assumes parallel trajectories of enactive and symbolic representations that do not interrelate to each other (for a similar view, see: Chomsky, 1968, 1975).

The discussed views make contradictory predictions on the developmental trajectories of interrelation between representations. These contradictory predictions were investigated in the present dissertation. My overall goal was to explore the functional and temporal interrelations between representations of action production, action perception and action language in early childhood. I further aimed at finding developmental trajectories of the interrelations in light of the discussed theories. Potential interrelations might be of different strength at different points in time. Therefore, children between the ages of 12 and 36 months of age were investigated in behavioral tasks, each combining two of the three action representations. This age window was chosen as it includes both, Piaget's sensorimotor and his preoperational stage and thus allows to investigate the functional relationship between action representations under a temporal notation.

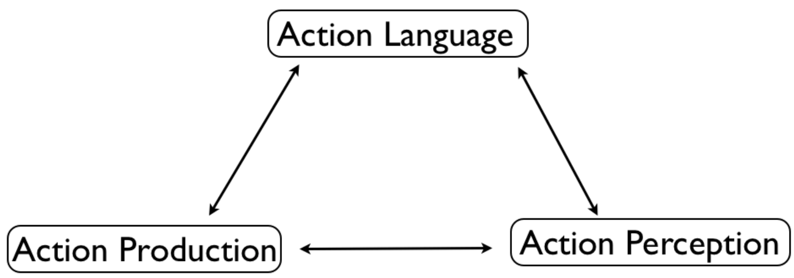


Figure 1: Illustration of potential temporal and functional interrelations between action production, action perception and action language.

# 2 Interrelations between Representations of Action

While the research on developmental interrelations between action representations is still in its infancy, research in adults is already well advanced. Existing studies on the interrelations between action production, action perception and action language in adulthood might be interesting for the developmental question under investigation. If interrelations between action representations exist in adulthood, then we can use it as starting point for developmental interrelations. If we know how interrelations can be detected, we can run similar studies in early development and might detect equalities, similarities, or differences in the way action production, action perception and action language work together.

## 2.1 Interrelations between action production and action perception

Action perception is one of the most important skills in social interactions. It allows us to understand the actions of others and to interact with others. Perceiving somebody getting a nail probably makes us thinking of a hammer and a hangable object coming next. We might then help this person in finding a hammer or look for a good place on the wall. A crucial question in this context is how the perception of actions works. How are we able to make sense of other´s actions? Do we abstractly process relevant information (a nail fits into a hole of mirror) or do we base our interpretation of other's action on our own experience (we have seen nails only in the contexts of somebody hammering something into the wall or we used nails in this way ourselves before)? The last possibility requires an interrelation between action production and action perception.

Thus, we now turn to theories on the interrelation between action production and action perception. Although different frameworks use different explanations, an overall agreement was established on the existence of a general interrelation between action production and action perception. I will introduce the “common-coding principle” of Wolfgang Prinz (1997) in more detail. Wolfgang Prinz wrote that “planned actions and perceived events share a common representational domain” (Prinz, 1997, p. 129). Although the contents of the perceptive representation and the productive representation are incommensurate, they are believed to translate into each other (Prinz, 1997, p. 130). It thus assumes that perceived events are linked to their corresponding motor code and performed action are linked to the perceptual event. This way action production and action perception share a neural substrate.

Such an approach further suggest facilitatory influences in congruent situations and interfering influences in incongruent situations. The theoretical “translation” and the shared neural substrate has been well supported by the discovery of mirror neurons in monkeys (Rizzolatti, Fadiga, Gallese, & Fogassi, 1996) and humans (Mukamel, Ekstrom, Kaplan, Iacoboni, & Fried, 2010). Mirror neurons are activated when an action is perceived and when the same action is produced (Iacoboni et al, 1999). This implies that even one and the same mirror neuron is activated in both domains, action production and action perception.

Taking this framework as bases, the perception of other's actions depends specifically on our own produced actions. This has been shown by a number of studies. In the domain of dancers for example: An expert dancer in classical ballet perceives another dancer in classical ballet differently than he perceives another dancer in capoeira (Calvo-Merino, Glaser, Passingham, & Haggard, 2005). Those actions the dancers have been trained to perform activated the motor cortex in the perception task greater than actions they had not been trained. Similar results on the influence of action production on action perception were made in further studies (Hamilton, Wolpert, & Frith, 2004; Jacobs & Shiffrar, 2005; Miall et al., 2006; Wühr & Müsseler, 2001). Another line of studies revealed influences of action perception on action production (Brass, Bekkering, & Prinz, 2001; Brass, Bekkering, Wohlschläger, & Prinz, 2000; Craighero, Bello, Fadiga, & Rizzolatti, 2002; Kilner, Paulignan, & Blakemore, 2003; Stürmer, Aschersleben, & Prinz, 2000). Taken together, these experimental findings support the common-coding principle and the implied reciprocal influences of action production and action perception.

In terms of our kitchen example mentioned above, this means that the way we adults observe others eating shares some representational content with the way we plan to eat on our own. The way we adults hammer nails ourselves shares some representational content with the way we observe others hammering nails into the wall. But an open question is still, is the production of an action necessary to interpret other's actions or does action production merely facilitates action perception? Investigating this question can be done by manipulate action types: actions that we already produce and action that we never have seen or done before. We will come back to this issue in chapter 4.

## 2.2 Interrelations between action production, action perception and language

Going back to action perception as an important skill for social interactions, we are often in situations in which actions are accompanied by linguistic information. We talk about things we want to do, about things we or others have done and things we or others are currently doing. Thus, such linguistic information is either given beforehand, simultaneously or after the action is already completed. But how does action perception with language work? Do we incorporate linguistic information when perceiving other's action? And do we incorporate linguistic information when we produce actions on our own?

Thus, we now turn to theories on the interrelation between action production, action perception and action language. According to the embodied view the interrelation between action production and action perception extends to the action language domain. The embodied view of language states that language is not an independent system or cognitive module but grounded in representations of actions in the individuals (Barsalou, 2008). Language comprehension is thus an activation of perceptual and motor experience but not an activation of abstract semantic or syntactic representations. Representations of action production and action perception are not independent of representations of action language. Hearing a word activates simultaneously the linguistic system and the simulation system. This way, representations of action production and action perception need to be linked to representations in action language and the auditive system. In other words: “The brain’s dictionary appears to be instantiated by means of a distributed network in which neuroanatomical structures that play a part in the immediate perception of objects […] as we view them, or the gestures associated with tools as we use them, are activated. The lexicon appears to connect real-world knowledge with the sound-patterns by which we communicate the concepts coded by words.” (Lieberman, 2002, p. 51).

Taking this framework as bases, the interpretation of action language depends on our own experience, on all of the produced and perceived actions. This has been shown by a number of studies. In the domain of verb processing for example: A verb related to actions performed with the face is encoded differently then a verb related to actions performed with the legs (Pulvermüller, Härle, & Hummel, 2001). Specifically, processing verbs related to face-actions (i.e., talk, bite, chew) caused motor activation over the left Sylvian fissure, responsible for carrying out face-actions whereas verb processing related to leg-actions (i.e., walk, jump, kick) caused motor activation in the vertex, responsible for carrying out leg-actions. These findings show a concrete connection between hearing action language and processing information relevant for action production. Another finding was made in the domain of action perception. When hearing a verb congruent to a perceived action our action prediction skills are enhanced (Springer & Prinz, 2010). Specifically, participants had to judge whether point-light-figure movement were correctly continued after an occlusion. The authors found that if the dynamics described by a written verb prior to the point-light-figures were congruent to the movement, participants made more correct judgements on the continuation of the movements than if the dynamics were incongruent. These findings show a concrete connection between language processing and processing information relevant for action perception. These two exemplary studies are supported by a number of other studies (e.g. Buccino et al., 2005; Glenberg & Kaschak, 2002; González et al., 2006; Hauk, Johnsrude, & Pulvermüller, 2004; Oliveri et al., 2004; Scorolli & Borghi, 2007), see Fischer and Zwaan (2008) for an overview. Taken together, the findings support the implied connection between representations in action production, action perception and action language in the embodied view of language. Furthermore, if the connection between these representations is impaired it leads to an impaired language understanding. Patients with Parkinson's disease suffer from motor disorders. These motor disorders lead to an impaired verb processing as the activation of the verb does not simultaneously causes the activation of the corresponding motor area (Boulenger et al., 2008). These results show that verb processing activates the motor area and this activation generates our interpretation of the verb. If the motor areas cannot be activated due to a disease verb processing is not successful.

In terms of our kitchen example this means, that hearing a verb like eating activates in adults part of the motor areas that are responsible for executing this action. Hearing a verb like hammering can facilitate adult's perception of hammering actions. But an open developmental question is still, whether and if so, how the perception of an grasping action changes once a child acquires a linguistic label for this action? Is a child only able to interpret action language if he/she has produced the action beforehand or is action production merely facilitating language processing? In order to investigate these questions one can also manipulate the action types: actions that we already produce and action that we never have seen or done before. In the same way we can manipulate label types in infancy: verbs that infants already produce and verbs that infants never heard or spoke before. We will come back to this issue in chapter 4.

# 3 Developmental Interrelations of between Representations of Action

As already touched lightly in the previous chapter, developmental studies allow us to answer some of the questions about the necessity of action production and action perception that could not yet be answered by research in adult action production and action perception. Additionally, results from developmental studies might additionally answer whether the interrelations between action production, action perception and action language develop over the first years of life or whether they do not interrelate at all. Does our perception of other's actions depend on the interrelation to our action production skills? Is language bound to our action production skills? Are children able to use these connections from early on or do they need time to mature?

We will now focus on experimental findings in infancy and childhood. While the interrelations between action production and action perception are widely investigated, no consensus was achieved on the question which representation would develop first. Work on the interrelation between action production, action perception and action language mainly investigated early relationships between action production and the first steps in language acquisition and little work was done in the transition phase between the sensorimotor and the preoperational phase.

## 3.1 Developmental interrelations between action production and action perception

With respect to the interrelations between action production and action perception, previous research has confirmed similar interrelations in infancy as in adulthood. Specifically, at the age of 6 months, infants' perception of a another's person goal-directed grasping action is mirrored by their grasping skills (M.M. Daum, Prinz, & Aschersleben, 2011). Furthermore, the onset of infants' ability to predict the goal of an observed grasping action was found to be linked to his/her own ability to execute the action (Kanakogi & Itakura, 2011). Similar findings were made in the area of reaching. Nine-month-olds reach for objects only ipsilaterally and interestingly follow other people when observing ipsilateral reaching movements but not contralateral ones (Longo & Bertenthal, 2006). However, at the age of 12 months, infants' production and perception of ipsi- and contralateral reaching movements are closely linked; anticipatory eye-movements of contralateral reachings were correlated to the production of such (Melzer, Prinz, & Daum, 2012). Other studies provided further evidence for the relation between the own execution of actions on a action perception task (Cannon, Woodward, Gredebäck, von Hofsten, & Turek, 2012; Gredebäck & Kochukhova, 2010; Hauf, Aschersleben, & Prinz, 2007). This interrelation has been supported by studies using electrophysiological measures (Nyström, 2008; van Elk, van Schie, Hunnius, Vesper, & Bekkering, 2008).

Apart from this general interrelation between action production and action perception, the question of whether there is a causal interrelation has caught much attention. Do skills in action production lead to skills in action perception or vice versa, do skills in action perception lead to skills in action production? As this causal interrelation can only hardly be investigated directly, it was mainly analyzed temporally. Which one is first: action production or action perception? The developmental order of the temporal interrelation between action production and action perception is controversial. Some researchers claim a production first hypothesis and others claim a perception first hypothesis.

The production first hypothesis assumes that infants produce actions before they are able to understand the same actions in others. According to this view, observed actions are simulated via the child's own motor system, which limits infants' action perception to human actions they are able to perform (Meltzoff & Moore, 1994; Woodward, 1998). More recent research in support of the production first hypothesis has shown that the acquisition of a certain motor skill changes the perception of the same motion performed by somebody else (Cannon et al., 2012; Longo & Bertenthal, 2006; Melzer et al., 2012; Sommerville, Woodward, & Needham, 2005). Sommerville and colleagues (2005) for instance trained one group of three-month-olds with sticky mittens before the perception task while another group performed this action only after the action perception task. Three-month old infants are not yet able to reach and the stimulation via sticky mittens leads to an action production representation that is not present in three-month-olds that did not participate in the study. The authors found that only those infants with this prior production experience were successful at perceiving the actions as goal-directed in the perception task.

In contrast, the perception first hypothesis assumes that infants can make use of a variety of perceptual cues in order to understand other's actions, that is their action perception. It is not limited to their own action repertoire. Rather, according to this view, action perception is innately based on pre-wired interpretative schemas triggered by distinct action-related cues. Such cues can be the self-propelledness of the agent, direction of the movement, efficiency of the action toward the goal and the presence of action effects (Gergely & Csibra, 2003; Johnson, Tucker, Stiles, & Trauner, 1998; Leslie, 1994; Premack, 1990). Recent research in support of the perception first hypothesis, and in conflict to the production first hypothesis, has shown that infants are able to perceive actions before having the respective production ability (Biro & Leslie, 2007; Daum, Vuori, Prinz, & Aschersleben, 2009; Gergely, Nádasdy, Csibra, & Bíró, 1995; Hofer, Hauf, & Aschersleben, 2005; Hofstadter & Reznick, 1996). Daum and colleagues (2009), for instance, designed a preferential looking time study in which 6-month-old infants were presented with expected and unexpected outcomes of a means-end action. The results showed that in the perception task, infants discriminated between the expected and the unexpected outcome of an observed means-end action. Additionally, this perceptual ability was independent of their actual competence in producing means-end behavior in the action task.

The two hypotheses have revealed contradictory evidence on the temporal and functional relationship between action production and action perception. Reasons for this might lie in the methods used. Mostly only one or two age groups were investigated and an artificial border between children with no action production competence and children with the respective action production competence were drawn. This can lead to displaced developmental trajectories. Furthermore only simple action skills, such as grasping and reaching are analyzed in isolation, which additionally causes constraints when modeling developmental growth. Study I therefore investigated the development of action perception and action production over a broad age range using complex multi-step actions.

### 3.1.1 Developmental interrelations between action production, action perception and action language

We now turn to the interrelations between action production, action perception and action language. Research in this field mainly focussed on the preverbal months and showed connections between action production and action language. Studies found that the developments of manipulating objects, performing gestures and producing the first words are tightly bound. For example, Thelen (1979) showed in a longitudinal study that the increase of rhythmic arm gestures correlated with reduplicated babbling. Furthermore, communicative pointing was found to be a good precursor for linguistic abilities (Bates, Benigni, Bretherton, Camaioni, & Volterra, 1979; Carpenter, Nagell, & Tomasello, 1998; Folven, Bonvillian, & Orlansky, 1984; Harris, Barrett, Jones, & Brookes, 1995) and the first words were shown to be influenced by the developmental skills in object deplacement (Lifter & Bloom, 1989). In addition, words for meanings expressed through recognitory gestures (Capirci, Contaldo, Caselli, & Volterra, 2005) and objects that are easy to manipulate (Nelson, 1973; Rodgon, Jankowski, & Alenskas, 1977) entered children's productive repertoire first. And finally, in the long run, the decrease of pointing gestures is correlated with an increase in the production of language (Stefanini, Bello, Caselli, Iverson, & Volterra, 2009). Thus, action production and the first productive words are interrelated in the early development.

Furthermore, we know that auditory speech and non-speech impacts on the perception of non-verbal tasks. Already 5-month-old infants are able to discriminate novel rhythms when they were habituated with a bimodal rhythm (auditory and visual information were presented in synchrony), which they could not when habituated only with unimodal information or when the synchrony was delayed (Bahrick & Lickliter, 2000). Additionally, linguistic information is also an important factor for category formation. Between the ages of 6 and 12 months, word phrases facilitate category formation (Balaban & Waxman, 1997; Fulkerson & Waxman, 2007). That is, when presented with two distinct labels for two distinct dinosaurs infants formed two categories, whereas when presented with one label for these two dinosaurs they formed only one category (Fulkerson & Waxman, 2007). Plunkett and colleagues (2008) extended these results in a different study by a further condition in which infants of 10 months heard two labels that were uncorrelated to the visual category, that is infants were presented with two labels for one and the same object. Those infants did not form any category (Plunkett et al., 2008). And even beyond the preverbal months, language shapes the way we perceive the world. Specifically, generalizations about object properties are still made by 14 and 22 months of age when accompanied by the same linguistic stimuli (Graham & Kilbreath, 2007). Taken together, these results show that labels have a strong impact on the categorization of objects in preverbal and verbal months. These studies are complemented by experimental studies showing that language influences action perception in the early development. Infants between 10 and 14 months of age look longest on objects that were labeled and simultaneously pointed at than objects that were presented without labeling (Baldwin & Markman, 1989). At the age of 10-months, infants make more errors in the A-not-B search task, if they observe the exchange in an ostensive-communicative situation (eye contact with the infant, smiling at and addressing him or her in infant-directed speech) as compared to a non-communicative one (Topál, Gergely, Miklósi, Erdöhegyi, & Csibra, 2008) Furthermore, at the age of 12 months, infants shift their covert attention in direction of a pointing gesture faster if the gesture was accompanied by ostensive language (Daum, Ulber,

& Gredebäck, in press). Finally, Miller and Marcovitch (2010) investigated the influence of language on executive function tasks. In a multistep multi-location search task 33-month old children were better at finding a hidden object if the picture on the hiding location has been linguistically marked by the experimenter and best if children marked it themselves linguistically (Miller & Marcovitch, 2010). Thus, the perception of objects and linguistic information interact with each other in the preverbal and first verbal months.

Taken together, the previous research revealed interactions between action production skills, such as rhythmic arm gestures, pointing, object displacement and the first productive words. It further pointed out how object perception was influenced by linguistic information in rhythm, object and category perception. But no studies were found on a specific connection between action language and action perception and production. So far, only the perception of pointing gestures was looked at under the influence of general ostensive language (Daum et al., in press). However, the discussed frameworks in adults assume a direct interrelation between a specific action label and the corresponding perception and production of this motion. Therefore, Study II investigated the direct influences of action labels on a corresponding action perception and Study III investigated the necessity of action production on learning a novel action label.

# 4 Experimental Studies

Having discussed possible frameworks and a series of studies in adults and children, we can now turn to some of the open questions that arose during the previous chapters. In particular, are children only able to interpret other's actions after they have produced the action themselves or is action production merely facilitating action perception? Which one is first: action production or action perception? Are children able to use action language to predict actions in infancy and if so, at which age? Are children only able to acquire action language if they have produced the action beforehand? What are the prerequisites for the interrelations between action production, action perception and action language to develop?

The studies summarized in the present dissertation investigated these questions in 12- to 36-month-old children and thus, the interrelations between representations of action production, action perception and action language in early childhood. It further aimed at describing the developmental trajectories of how action production, action perception and action language are interrelated. Potential interrelations might be of different strength at different points in time (Thelen & Smith, 2007) as development is no static product but a dynamic process of constantly changing priorities. In each of the studies children were presented with behavioral tasks, each combining two of the three action representations, see Figure 2. This way, I explored interrelations between action production and action perception (Study I), interrelations between action perception and action language (Study II) and finally, interrelations between action production and action language (Study III). Children's perception and production of both familiar and unfamiliar actions and language was investigated in all studies. The rationale for this is that manipulating the action types and languages types allows drawing inferences about the temporal and causal interrelations between the representations.

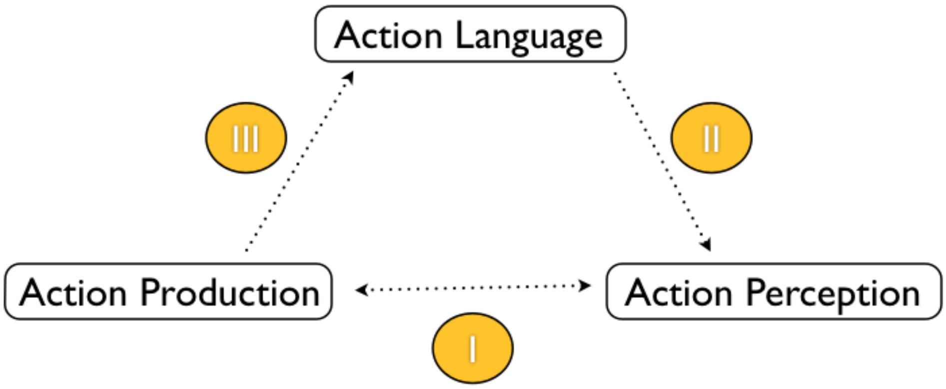


Figure 2: Investigated interrelations between action production, action perception and action language.

### 4.1 Experimental study on the interrelation between action production and action perception

Study I focussed on the causal interrelations between action production and action perception. Having the contradictory hypothesis and previous experimental findings on the temporal order of the development of action production and action perception as given, I aimed at investigating the interrelation in a more developmental manner over a wider age range. Doing so allows assertions on the developmental trajectories. From these developmental trajectories one can then make conclusion on the temporal order of action production and action perception. Furthermore, I used more complex actions than previous studies that involved several sub-action of different difficulty in order to increase the ecological validity and to reveal more detailed functional interrelations.

In a combined 'action perception - action production' task the developmental trajectories and their interrelation were evaluated. Children from 12 to 30 months of age saw familiar and novel multi-step actions (grasping, transporting, tool grasping, tool execution) on an eyetracker and were given the material afterwards. The skills in action perception and action production were measured by their anticipation frequency and their imitation / emulation performance. From a general perspective I expected the children to increase their performance in action production and action perception over age. Concerning the temporal order, the expectations were different for the two existing hypothesis. In the case that the perception first hypothesis holds true, children would be able to predict actions before they could actually imitate them and they had not seen or produced before (Daum et al., 2009; Hofer et al., 2005; Hofstadter & Reznick, 1996). In contrast, in case the production first hypothesis holds true children would only after having acquired the imitation competence be able to predict the corresponding action and they would be unable to predict novel actions (Cannon et al., 2012; Longo & Bertenthal, 2006; Melzer et al., 2012; Sommerville et al., 2005).

The results revealed a general interrelation between action production and action perception: children's anticipation frequencies were correlated with their imitation/emulation scores. With respect to the ontogenetic order of action production and action perception, for familiar actions it was found that action perception preceded action production. The anticipation frequency reached an age-related plateau already at the age of 18 months, whereas the imitation/emulation score reached its plateau at the age of 24 months. For novel actions it was found that action perception and action production developed in parallel. Both the anticipation frequency and the imitation/emulation score reach their plateau at 24 months. With respect to the functional interrelation between action production and action perception, two types of sub actions were compared: namely the non-tool actions (grasping, transporting) and the tool actions (tool grasping, tool execution). Children's anticipation frequencies showed no differentiation between tool and non-tool sub actions before the age of 30 months, that is, after they reach a plateau in imitation. Thus action production was necessary to differentiate in action perception while action production was not necessary to predict the action.

The findings of Study I might be interpreted in this way: An interrelation between action production and action perception exists between the ages of 12 and 30 months. Furthermore, children are able to perceive and predict actions they have never seen beforehand in the same way, as they are able to perceive actions they have seen beforehand. This implies the use of inferential cues, such as the self-propelledness of the agent, direction of the movement, efficiency of the action toward the goal and the presence of action effects (Gergely & Csibra, 2003; Johnson et al., 1998; Leslie, 1994; Premack, 1990). But once, children are able to produce these actions, the perception of this action is altered. Action production thus affects action perception. The simple question after the temporal order of action production and action perception cannot be answered in a simple way. Depending on which actions are looked at and which age groups are investigated the answers change.

### 4.1.1 Experimental study on the interrelation between action perception and action language

Study II focussed on the interrelations between action language and action perception. Since previous research demonstrated the influential impact of action language on action prediction in adulthood (Springer & Prinz, 2010) and a similar study in 10-year-old children (Nation, Marshall, & Altmann, 2003), I aimed at analyzing the direct interrelation between a specific action label and the corresponding action perception in early development. Specifically, I was curious at the following questions: At what age are children able to use language for action prediction? Is a language specific impact existent in the early months of language acquisition or in a more advanced phase of language production? And what prerequisites are required? Does the impact depend on the age or on the knowledge for the specific item in question?

Study II used an eye-tracking paradigm, a combination of the paradigms used by Springer & Prinz (2010) and Nation and colleagues (2003). I explored the effect of a specific action label on the subsequent perception of the corresponding action. Children between 12 and 24 months of age heard a sentence containing a verb and then saw a short action video. I measured the anticipation times in the action video and then compared the influence of the linguistic input on action prediction. I used a baseline sentence condition containing no verb as benchmark to a familiar verb label condition and a novel verb control condition containing pseudowords. In order to investigate the question after the prerequisites necessary for a potential influence of action labels on action perception, I manipulated the ages of acquisition of the verbs presented. Using normative data on the acquisition of language (Szagun, Stumper, & Schramm, 2009), I generated early verbs' actions and late verbs' actions. Early acquired verbs were already produced by the majority of the 24-month-olds, whereas late acquired verbs were first produced by the majority of 30-month-old children but were in the perceptive repertoire of the 24 month olds. Additionally, novel control actions were employed. My hypothesis were the following: First, if language impacts on action perception, I would expect that children's looking behavior indicate that they predicted an action faster in the familiar label condition than in the baseline label condition. If this was the case, it might either happen in the early months of language acquisition at 12 months if the interrelation is already present or in a more advanced phase of language production at 24 months if the interrelation needs prerequisites. Second: if age, rather than specific verb knowledge (as manipulatied by AOA) is the crucial factor determining an influence of language on action perception, then no age of acquisition effect should be found; the facilitation effect in the familiar label condition should be independent of whether a respective verb is acquired early or late. In contrast, if the impact is item-specific, a facilitation effect in the label condition should be found at an earlier age for early acquired words, and at a later age for late-acquired words.

Results suggest that children in all age groups processed the linguistic verbal information in combination with the action information. But the influence of language changes. Familiar labels interfered with the perception of 12-month-old infants whereas they facilitated the perception of 24-month-old infants. This speaks for a gradual integration of language as additional source of information in action perception. However, this was only true for the early acquired labels. The late acquired labels did not lead to significant difference from the baseline in any age group.

The findings of Study II showed a developmental process in the ability to use language to predict actions. While 12-month-olds processed the linguistic information, they were not yet able to use it in a beneficial way. It took further 12 months until children used the linguistic information to predict actions faster. This resulted in a facilitation of action perception. But not all verbs could be processed in this facilitatory way. Only those verbs that were already in the productive repertoire of the children showed this effect. The results suggest a item-specific communication between action language and action perception if language is on a perceptive level and an item-specific interrelation between action language and action perception if language is on a productive level.

## 4.2 Experimental study on the interrelation between action production, action perception and action language

Study III focussed on the interrelations between action production and action language. Based on earlier research that demonstrated a general interrelation between motor acts and linguistic abilities and a study on word learning in novel languages in adulthood (Macedonia & Knösche, 2011), I was interested in the following questions: Do children need to produce an action before the corresponding label for this action can be learned? Or is action perception sufficient for learning labels?

It was investigated whether 24- to 36-month-old children's success in verb learning differed between situations in which they heard a novel verb after only perceiving the action (passive condition) or after perceiving and producing the action (active condition). Two different actions types were used in the study, object actions with focus on the object couplings using the same movement and motion actions with focus on both object properties and movement information. Children perceived (and performed) three different actions on objects for three times, while one of these actions was labeled by a novel label. In the test phase, children got all three objects and were asked to show the action that was linked to the novel label. I coded whether children took the correct object and whether they performed the correct action. Based on previous research, I hypothesized that the production of an object action in the active condition would not enrich the linguistic representation and thus not influence the learning of verbal labels (Behrend, 1990; Forbes & Farrar, 1995; Kersten & Smith, 2002). In contrast, the production of a motion action should enrich the linguistic representation in the active condition and facilitate the learning of the verbal labels (Macedonia & Knösche, 2011).

Results showed that indeed verb learning for object actions did not differ between the active and the passive condition. However, verb learning in motion actions was clearly affected by the production of the action in the active condition. Twenty-four and 30-month-old children learned more parts of the language concepts (only action correct or only object correct) in the active condition. Children at the same age in the passive condition either the whole concept (action and object correct) or learned nothing (action and object wrong). And while 30-month-olds learned the novel label in the active condition, 30-month-olds did not learn the novel label in the passive condition. At the age of 36 months children were in both conditions good verb learners and the differences between the conditions diminished.

The findings of Study III showed a developmental process here as well. At the beginning of word learning the ability to transfer a perceived action into a produced action is a major prerequisite of verb learning. Only the labels of "easy" object actions, but not the labels of "harder" motion actions could be learned at the age of 24 months. Additional to the transfer ability actual action production leads to an advance in verb learning of 6 months. Only at the age of 36 months does actual action production not result in a better verb learning. In terms of the interrelations between language and action, the results suggest a strong communication between language and production. Linguistic concepts can only be acquired if the respective actions could exist as productive action representations. Furthermore do productive action representations facilitate the acquisition new linguistic concepts. Later in development is a perceptive action representation enough to acquire a linguistic concept.

# 5 Discussion & Implications

The present dissertation investigated the interrelations between action production, action perception and action language in children between 12 and 36 months of age. If we now turn back to the questions that were the starting point of the dissertation, several answers can be made from the findings in the experimental studies. Starting with the first two related questions: Are children only able to interpret other's actions after they have produced the action ourselves or is action production merely facilitating action perception? Which one is first: action production or action perception? The findings of Study I showed that the perception of novel and familiar actions is equally possible while it is differentiated once the production ability comes in. Concerning the temporal order, in familiar actions a perception advance was found while in novel actions, a parallel development was found. Proceeding to the second question: Are we able to use action language to predict actions in infancy? The findings of Study II showed a developmental process in the ability to use language to predict actions. The results thus suggest a item-specific communication between action language and action perception if language is on a perceptive level and an item-specific facilitation between action language and action perception if language is on a productive level. Closing with the third question: Are we only able to interpret action language if we have produced the action beforehand? The findings of Study III showed a developmental process here as well. At the beginning of word learning the ability to transfer a perceived action into a produced action is a major prerequisite of verb learning and action production leads to an advance in verb learning of 6 months. Later in development is a perceptive action representation enough to acquire a linguistic concept.

As it was shown, interrelations between action representations are part of the developmental course and they change over the developmental course. The current dissertation focused on interrelations between action production, action perception and action language in the domain of already established concepts and in the domain of newly introduced concepts. In both domains, interrelations occur frequently and change the status of their interrelation over the developmental course. The findings of the studies reported in this dissertation showed that action perception and action production are interrelated with action production influencing action perception. This finding might be interpreted as speaking for the involvement of an adult-like shared representation between action perception and action production (Prinz, 1997) that is not based on long years of experience but builds for all actions children are faced with. As for the interrelation between action production, action perception and action language in the domain of established concepts, I was able to demonstrate that from 12 months on, productive but not receptive knowledge of action language facilitates prediction of the same action. Before this stage of facilitation, the representations communicate with each other in case the label is on a perceptive level. In the domain of novel concepts, I was able to show that linguistics concepts can only be acquired for actions that can be reproduced. If the reproduction of actions is possible the actual action production facilitates the acquisition of novel labels at the ages of 24 and 30 months and later in development, at the age of 36 months, action perception is sufficient for the acquisition. Both findings might as well be interpreted as suggesting the involvement of an adult-like shared representation between action production, action perception and action language that depend on stable representations in the single representations.

Coming back to the developmental theories on cognitive growth, the interrelations revealed in the studies of this dissertation can be summarized with respect to their ontogenetic order, see Figure 3. When taking Piaget's stages as bases, in the sensorimotor stage 12 and 18 month-old infants were analyzed in Studies I and II. In the preoperational stage 24, 30 and 36 month old children were analyzed in Studies I, II and III. At 12 months, children's action production abilities were linked to their action perception abilities and action language had an interfering influence on action perception. At 18 months, children's action production abilities were also linked to their action perception abilities and the interfering influence of language was revoked. At 24 months, again children's action production abilities were linked to their action perception abilities, but additionally, action language was now facilitating action perception and action production was beneficial for learning action language. At 30 months, the same link between action production and action perception was found as in previous age groups. Furthermore, skills in action production now lead to a differentiated action perception. Beyond these findings, action production was again beneficial for learning action language. At 36 months, children benefited not further from action production in verb learning.

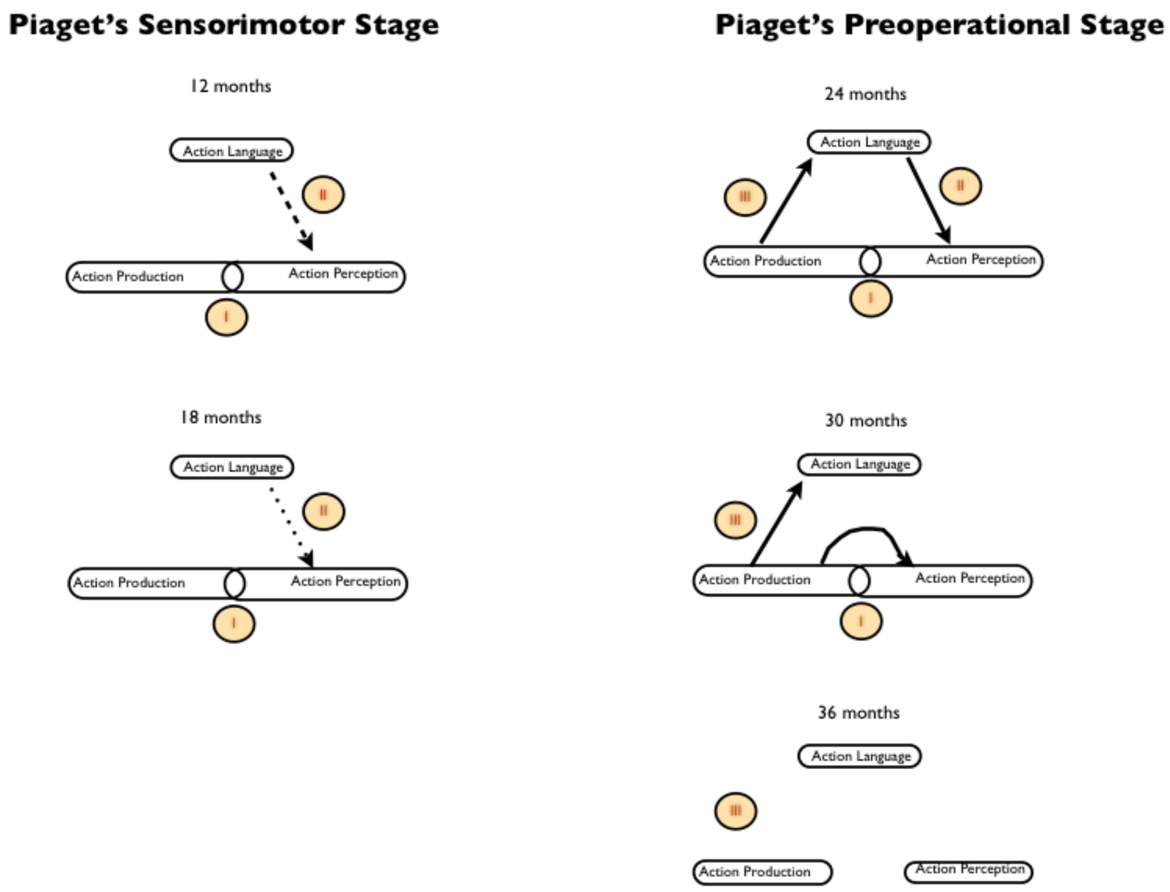


Figure 3: Interrelations found in the experimental studies I, II and III between the ages of 12 and 36 months.

The results support the theory of Piaget who emphasized the role of sensorimotor representations in learning to understand given concepts and construct new concepts. This process seems to play a central role at the beginning. The process was demonstrated in both the sensorimotor and the preoperational stage and turns into a more automatic act over the developmental course of the preoperational stage. This is also in line with Vygotsky's theory who emphasizes the role of social interaction in learning (Vygotsky, 1987). Through perceiving other's action and performing them themselves, children become social agents in the world. None of the results speak for a parallel and independent development of sensorimotor and conceptual representations, as proposed by Mandler (1988) or in the modular approach by Chomsky (1951; 1967). The results are further in line with the assumptions of the dynamic systems approach (Thelen & Smith, 2007). Dynamic systems is a theoretical approach that explains how development might work in terms of "multiple, mutual and continuous interactions of all levels of the developing system" (Thelen & Smith, 2007, p.

258) and as “nested processes that unfold over many timescales” (Thelen & Smith, 2007, p. 258). New concepts are then formed by self-organization in which patterns and orders develop from interactions of the components (Thelen & Smith, 1994). “Learning and development - consist of finding a pathway or discovering a new niche in the life space. And as children carve new pathways, they actually create yet new parts of the space to explore, a process of self-organization” (Thelen & Smith, 2007, p. 268).

Closing with Alina, the young girl of 24 months of age, and the questions that arose for her everyday interaction with her parents. We can now tell, that the representation of Alina’s eating shares some content with the representation of her mother’s eating. In case of rather novel actions like hammering the common information of both representations is less strong and more goal-fixated. In both cases experience in performing the actions herself strengthens the perceptual discrimination ability. We can further tell, that linking action representations like eating and hammering to their linguistic representations depends on the successful acquisition of both representations on a productive level. For the acquisition of novel linguistic representations action representations are beneficial for the 2-year-old Alina while this importance diminish in the course of time.

Making sense of other's actions and language has been shown to be a complex task with changing influences at different points of time. Action production can in both cases help to make good judgements. It is thus one of the most powerful ways to act and interact in our social world and it opens new pathways in the complex knot garden of everyday life.

# References

Bahrick, L. E., & Lickliter, R. (2000). Intersensory redundancy guides attentional selectivity and perceptual learning in infancy. *Developmental Psychology*, *36*(2), 190–201. doi:10.1037/0012-1649.36.2.190

Balaban, M. T., & Waxman, S. R. (1997). Do Words Facilitate Object Categorization in 9-Month-Old Infants? *Journal of Experimental Child Psychology*, *64*(1), 3–26. doi:10.1006/jecp.1996.2332

Baldwin, D. A., & Markman, E. M. (1989). Establishing word-object relations: A first step. *Child Development*, *60*, 381–398.

Barsalou, L. W. (2008). Grounded cognition. *Annual Review of Psychology* (Vol. 59, pp. 617–645). Palo Alto: Annual Reviews.

Bates, E., Benigni, L., Bretherton, I., Camaioni, L., & Volterra, V. (1979). *The emergence of symbols: Cognition and communication in infancy.* New York: Academic Press.

Behrend, D. (1990). The Development of Verb Concepts - Childrens Use of Verbs to Label Familiar and Novel Events. *Child Development*, *61*(3), 681–696. doi:10.1111/j.1467-8624.1990.tb02811.x

Biro, S., & Leslie, A. M. (2007). Infants' perception of goal-directed actions: development through cue-based bootstrapping. *Developmental Science*, *10*(3), 379–398. doi:10.1111/j.1467-7687.2006.00544.x

Boulenger, V., Mechtouff, L., Thobois, S., Broussolle, E., Jeannerod, M., & Nazir, T. A. (2008). Word processing in Parkinson's disease is impaired for action verbs but not for concrete nouns. *Neuropsychologica*, *46*, 743–756.

Brass, M., Bekkering, H., & Prinz, W. (2001). Movement observation affects movement execution in a simple response task. *Acta Psychologica*, *106*(1–2), 3–22. doi:10.1016/S0001-6918(00)00024-X

Brass, M., Bekkering, H., Wohlschläger, A., & Prinz, W. (2000). Compatibility between Observed and Executed Finger Movements: Comparing Symbolic, Spatial, and Imitative Cues. *Brain and Cognition*, *44*(2), 124–143. doi:10.1006/brcg.2000.1225

Bruner, J. S. (1964). The course of cognitive growth. *American Psychologist*, *19*(1), 1–15. doi:10.1037/h0044160

Buccino, G., Riggio, L., Melli, G., Binkofski, F., Gallese, V., & Rizzolatti, G. (2005). Listening to action-related sentences modulates the activity of the motor system: A combined TMS and behavioral study. *Cognitive Brain Research*, *24*, 355–363.

Calvo-Merino, B., Glaser, D. E., Passingham, R. E., & Haggard, P. (2005). Action Observation and Acquired Motor Skills: An fMRI Study with Expert Dancers. *Cerebral Cortex*, *15*, 1243–1249.

Cannon, E. N., Woodward, A. L., Gredebäck, G., von Hofsten, C., & Turek, C. (2012). Action production influences 12-month-old infants' attention to others' actions. *Developmental Science*, *15*, 35–42. doi:10.1111/j.1467-7687.2011.01095.x

Capirci, O., Contaldo, A., Caselli, M. C., & Volterra, V. (2005). From action to language through gesture: A longitudinal perspective. *Gesture*, *5*(1-2), 155–177. doi:10.1075/gest.5.1.12cap

Carpenter, M., Nagell, K., & Tomasello, M. (1998). Social cognition, joint attention, and communicative competence form 9 to 15 months of age. *Monographs of the Society for Research in Child Development.*, *63*, V–143.

Chomsky, N. (1968). *Language and mind*. New York [u.a.]: Harcourt, Brace & World.

Chomsky, N. (1975). *Questions of form and interpretation*. PdR Press publication in philosophy of language ; 4. Lisse: de Ridder Pr.

Craighero, L., Bello, A., Fadiga, L., & Rizzolatti, G. (2002). Hand action preparation influences the responses to hand pictures. *Neuropsychologia*, *40*(5), 492–502. doi:10.1016/S0028-3932(01)00134-8

Daum, M.M., Prinz, W., & Aschersleben, G. (2011). Perception and production of object-related grasping movements in 6-month-old infants. *Journal of Experimental Child Psychology*, *108*, 810–818.

Daum, M.M., Ulber, J., & Gredebäck, G. (in press). The development of pointing comprehension in infancy: Communicative speech supports shifts of covert attention. *Developmental Psychology*.

Daum, Moritz M, Vuori, M. T., Prinz, W., & Aschersleben, G. (2009). Inferring the size of a goal object from an actor's grasping movement in 6- and 9-month-old infants. *Developmental science*, *12*(6), 854–862. doi:10.1111/j.1467-7687.2009.00831.x

Fischer, M. H., & Zwaan, R. A. (2008). Embodied language: A review of the role of the motor system in language comprehension. *The Quarterly Journal of Experimental Psychology*, *61*(6), 825–850. doi:10.1080/17470210701623605

Folven, R. J., Bonvillian, J. D., & Orlansky, M. D. (1984). Communicative gestures and early sign language acquisition. *First Language*, *5*, 129–143.

Forbes, J., & Farrar, M. (1995). Learning to Represent Word Meaning - What Initial Training Events Reveal About Childrens Developing Action Verb Concepts. *Cognitive Development*, *10*(1), 1–20. doi:10.1016/0885-2014(95)90016-0

Fulkerson, A. L., & Waxman, S. R. (2007). Words (but not Tones) facilitate object categorization: Evidence from 6- and 12-month-olds. *Cognition*, *105*(1), 218–228. doi:10.1016/j.cognition.2006.09.005

Gallistel, C R. (1989). Animal Cognition: The Representation of Space, Time and Number. *Annual Review of Psychology*, *40*(1), 155–189. doi:10.1146/annurev.ps.40.020189.001103

Gallistel, Charles R. (1990). *The organization of learning*. Learning, development, and conceptual change. (Vol. viii). Cambridge, MA, US: The MIT Press.

Gergely, G., & Csibra, G. (2003). Teleological reasoning in infancy: the naïve theory of rational action. *Trends in Cognitive Sciences*, *7*(7), 287–292. doi:10.1016/S1364-6613(03)00128-1

Gergely, G., Nádasdy, Z., Csibra, G., & Bíró, S. (1995). Taking the intentional stance at 12 months of age. *Cognition*, *56*(2), 165–193. doi:10.1016/0010-0277(95)00661-H

Glenberg, A. M., & Kaschak, M. P. (2002). Grounding language in action. *Psychonomic Bullentin & Review*, *9*, 558–565.

González, J., Barros-Loscertales, A., Pulvermüller, F., Meseguer, V., Sanjuán, A., Belloch, V., & Ávila, C. (2006). Reading cinnamon activates olfactory brain regions. *NeuroImage*, *32*(2), 906–912. doi:10.1016/j.neuroimage.2006.03.037

Graham, S. A., & Kilbreath, C. S. (2007). It's a sign of the kind: Gestures and words guide infants' inductive inferences. *Developmental Psychology*, *43*(5), 1111–1123. doi:10.1037/0012-1649.43.5.1111

Gredebäck, G., & Kochukhova, O. (2010). Goal anticipation during action observation is influenced by synonymous action capabilities, a puzzling developmental study. *Experimental Brain Research*, *202*(2), 493–497. doi:10.1007/s00221-009-2138-1

Hamilton, A., Wolpert, D., & Frith, U. (2004). Your Own Action Influences How You Perceive Another Person's Action. *Current Biology*, *14*(6), 493–498. doi:10.1016/j.cub.2004.03.007

Harris, M., Barrett, M., Jones, D., & Brookes, S. (1995). The emergence of referential understanding: Pointing and the comprehension of names. *First Language*, *15*, 19–34.

Hauf, P., Aschersleben, G., & Prinz, W. (2007). Baby do - baby see! How action production influences action perception in infants. *Cognitive Development*, *22*, 16–32.

Hauk, O., Johnsrude, I., & Pulvermüller, F. (2004). Somatotopic Representation of Action Words in Human Motor and Premotor Cortex. *Neuron*, *41*(2), 301–307. doi:10.1016/S0896-6273(03)00838-9

Hofer, T., Hauf, P., & Aschersleben, G. (2005). Infant's perception of goal-directed actions performed by a mechanical device. *Infant Behavior and Development*, *28*(4), 466–480. doi:10.1016/j.infbeh.2005.04.002

Hofstadter, M., & Reznick, J. S. (1996). Response Modality Affects Human Infant Delayed-Response Performance. *Child Development*, *67*(2), 646–658. doi:10.1111/j.1467-8624.1996.tb01757.x

Jacobs, A., & Shiffrar, M. (2005). Walking Perception by Walking Observers. *Journal of Experimental Psychology: Human Perception and Performance*, *31*(1), 157–169. doi:10.1037/0096-1523.31.1.157

Johnson, M. H., Tucker, L. A., Stiles, J., & Trauner, D. (1998). Visual attention in infants with perinatal brain damage: Evidence of the importance of anterior lesions. *Developmental Science*, *1*(1), 53–58. doi:10.1111/1467-7687.00012

Kanakogi, Y., & Itakura, S. (2011). Developmental correspondence between action prediction and motor ability in early infancy. *Nature Communications*, *2*, 1–6.

Kersten, A. W., & Smith, L. B. (2002). Attention to novel objects during verb learning. *Child Development*, *73*(1), 93–109. doi:10.1111/1467-8624.00394

Kilner, J. ., Paulignan, Y., & Blakemore, S. . (2003). An Interference Effect of Observed Biological Movement on Action. *Current Biology*, *13*(6), 522–525. doi:10.1016/S0960-9822(03)00165-9

Kosslyn, S. M. (1978). The representational-development hypothesis. In P. A. Ornstein (Ed.), *Memory development in children*. Hillsdale, NJ: Erlbaum.

Leslie, A. M. (1994). ToMM, ToBy, and agency: Core architecture and domain specificity. In L. A. Hirschfeld & S. A. Gelman (Eds.), *Domain-specificity in cognition and culture*. New York: Cambridge University Press.

Lieberman, P. (2002). On the nature and evolution of the neural bases of human language. *American Journal of Physical Anthropology*, *119*(S35), 36–62. doi:10.1002/ajpa.10171

Lifter, K., & Bloom, L. (1989). Object knowledge and the emergence of language. *Infant Behavior and Development*, *12*(4), 395–423. doi:10.1016/0163-6383(89)90023-4

Longo, M. R., & Bertenthal, B. I. (2006). Common coding of observations and execution of action in 9-month-old infants. *Infancy*, *10*, 43–59.

Macedonia, M., & Knösche, T. R. (2011). Body in Mind: How Gestures Empower Foreign Language Learning. *Mind, Brain, and Education*, *5*(4), 196–211. doi:10.1111/j.1751-228X.2011.01129.x

Mandler, J. M. (1988). How to build a baby: On the development of an accessible representational system. *Cognitive Development*, *3*(2), 113–136. doi:10.1016/0885-2014(88)90015-9

Meltzoff, A. N., & Moore, K. M. (1994). Imitation, memory, and the representation of persons. *Infant Behavior and Development*, *17*(1), 83–99. doi:10.1016/0163-6383(94)90024-8

Melzer, A., Prinz, W., & Daum, M. M. (2012). Production and perception of contralateral reaching: A close link by 12 months of age. *Infant behavior & development*, *35*(3), 570–579. doi:10.1016/j.infbeh.2012.05.003

Miall, R. C., Stanley, J., Todhunter, S., Levick, C., Lindo, S., & Miall, J. D. (2006). Performing hand actions assists the visual discrimination of similar hand postures. *Neuropsychologia*, *44*(6), 966–976. doi:10.1016/j.neuropsychologia.2005.09.006

Miller, S. E., & Marcovitch, S. (2010). Toddlers benefit from labeling on an executive function search task. *Journal of Experimental Child Psychology*, *108*, 580–592.

Mukamel, R., Ekstrom, A. D., Kaplan, J., Iacoboni, M., & Fried, I. (2010). Single-Neuron responses in humans during execution and observation of actions. *Current Biology*, *20*, 750–756.

Nation, K., Marshall, C. M., & Altmann, G. T. . (2003). Investigating individual differences in children's real-time sentence comprehension using language-mediated eye movements. *Journal of Experimental Child Psychology*, *86*(4), 314–329. doi:10.1016/j.jecp.2003.09.001

Nelson, K. (1973). Structure and Strategy in Learning to Talk. *Monographs of the Society for Research in Child Development*, *149*(1-2), 1–138.

Nyström, P. (2008). The infant mirror neuron system studied with high density EEG. *Social Neuroscience*, *3*, 334–347.

Oliveri, M., Finocchiaro, C., Shapiro, K., Gangitano, M., Caramazza, A., & Pascual-Leone, A. (2004). All Talk and No Action: A Transcranial Magnetic Stimulation Study of Motor Cortex Activation during Action Word Production. *Journal of Cognitive Neuroscience*, *16*(3), 374–381. doi:10.1162/089892904322926719

Palmer, S. E. (1978). Fundamental aspects of cognitive representation. In E. Rosch & B. B. Lloyd (Eds.), *Cognition and categorization*. Hillsdale.

Piaget, J. (1951). *Play, dreams and imitation in childhood Transl. by C. Gattegno and F. M. Hodgson: Transl. by C. Gattegno and F. M. Hodgson*. London: Routledge & Kegan Paul.

Piaget, J. (1967). *The language and thought of the child*. Cleveland: Word-Publishing.

Piaget, J., & Inhelder, B. (1966). *La psychologie de l'enfant*. Paris: Presses Univ. de France.

Plunkett, K., Hu, J.-F., & Cohen, L. B. (2008). Labels can override perceptual categories in early infancy. *Cognition*, *106*(2), 665–681. doi:10.1016/j.cognition.2007.04.003

Premack, D. (1990). The infant's theory of self-propelled objects. *Cognition*, *36*(1), 1–16. doi:10.1016/0010-0277(90)90051-K

Prinz, W. (1997). Perception and action planning. *European Journal of Cognitive Psychology*, *9*, 129–154.

Pulvermüller, F., Härle, M., & Hummel, F. (2001). Walking or talking?: behavioral and neurophysiological correlates of action verb processing. *Brain and Language*, *78*, 143–168.

Rizzolatti, G., Fadiga, L., Gallese, V., & Fogassi, L. (1996). Premotor cortex and the recognition of motor actions. *Cognitive Brain Research*, *3*, 131–141.

Rodgon, M. M., Jankowski, W., & Alenskas, L. (1977). A multi-functional approach to single-word usage. *Journal of Child Language*, *4*(01), 23–43. doi:10.1017/S0305000900000465

Scorolli, C., & Borghi, A. M. (2007). Sentence comprehension and action: Effector specific modulation of the motor system. *Brain Research*, *1130*(0), 119–124. doi:10.1016/j.brainres.2006.10.033

Sommerville, J. A., Woodward, A. L., & Needham, A. (2005). Action experience alters 3-month-old infants' perception of others' actions. *Cognition*, *96*, B1–B11.

Springer, A., & Prinz, W. (2010). Action semantics modulate action prediction. *The Quarterly Journal of Experimental Psychology*, *63*, 2141–2158.

Stefanini, S., Bello, A., Caselli, M. C., Iverson, J., & Volterra, V. (2009). Co-Speech gestures in a naming task: Developmental data. *Language and Cognitive Processes*, *24*, 168–189.

Stürmer, B., Aschersleben, G., & Prinz, W. (2000). Correspondence effects with manual gestures and postures: A study of imitation. *Journal of Experimental Psychology: Human Perception and Performance*, *26*(6), 1746–1759. doi:10.1037/0096-1523.26.6.1746

Szagun, G., Stumper, B., & Schramm, A. S. (2009). Fragebogen zur frühkindlichen Sprachentwicklung (FRAKIS) und FRAKIS-K (Kurzform). *Frankfurt: Pearson Assessment*.

Thelen, E. (1979). Rhythmical Stereotypies in Normal Human Infants. *Animal Behaviour*, *27*(AUG), 699–715. doi:10.1016/0003-3472(79)90006-X

Thelen, Esther, & Smith, L. B. (2007). Dynamic Systems Theories. *Handbook of Child Psychology*. John Wiley & Sons, Inc. Retrieved from http://onlinelibrary.wiley.com/doi/10.1002/9780470147658.chpsy0106/abstract

Topál, J., Gergely, G., Miklósi, Á., Erdöhegyi, Á., & Csibra, G. (2008). Infants' perseverative search errors are induced by pragmatic misinterpretation. *Science*, *321*, 1831–1834.

van Elk, M., van Schie, H. T., Hunnius, S., Vesper, C., & Bekkering, H. (2008). You'll never crawl alone: neurophysiological evidence for experience-dependent motor resonance in infancy. *NeuroImage*, *43*.

Vygotsky, L. (1987). *The collected works of L.S. Vygotsky: Vol. 1. Problems of generel psycholgy.* New York: Plenum Press.

Werner, H. (1926). *Einführung in die Entwicklungspsychologie*. Leipzig: Barth.

Woodward, A. L. (1998). Infants selectively encode the goal object of an actor's reach. *Cognition*, *69*, 1–34.

Wühr, P., & Müsseler, J. (2001). Time course of the blindness to response-compatible stimuli. *Journal of Experimental Psychology: Human Perception and Performance*, *27*(5), 1260–1270. doi:10.1037/0096-1523.27.5.1260

# PART II

# 6 What comes first? Temporal and functional relationships between action perception and production

Abstract

Research on the development of the relationship between perception and production has revealed inconclusive results. A still unresolved issue is whether the common representational system for perception and production is an innate endowment or a developmental achievement. We explored the long-term developmental course of perception and production with actions that involved familiar and novel skills. In a combined perception and production task children were tested over a broad age range between the ages of 12 and 30 months. We measured the prediction frequency for perception and imitation/emulation scores for production. We found that the ability to predict an action goal was highly correlated to the ability to imitate the observed action independent of age. Second, in familiar actions prediction preceded imitation/emulation whereas in the novel action, prediction and imitation/emulation developed simultaneously. While children imitated the non-tool action steps better then the tool-action steps their predictions of the non-tool and tool action steps did not differ between 12 and 24 months of age. Only at 30 months of age they showed a faster prediction of the non-tool action steps. The answers of our study suggest a reciprocal development of perception and production with each of the two influencing the respective other one.

## 6.1 Introduction

Infant cognition is social cognition to a great extent. Through social interactions, children learn to understand the world; they learn about the function of objects and to understand action goals, intentions, beliefs and desires. Through these developmental milestones, infants become social agents able to act and interact with their physical and social environment. Any engagement in cooperative and communicative activity within a dynamic environment requires correct interpretation and prediction of others' actions (henceforth called perception) as well as appropriate control of one's own actions (production).

Numerous studies with human adult or monkey populations have shown that perception and production are not separate entities but are closely linked, resulting in frameworks such as the common-coding principle (Prinz, 1997), simulation theory (Jeannerod, 2001), or the mirror neuron system hypothesis (Rizzolatti & Craighero, 2004). These frameworks all share, at least to some degree, the idea that perception is mediated by production through the motor system. In order to understand somebody doing something, our motor system draws on stored information and simulates the perceived action in order to predict and interpret the observed action.

Research on the development of the relationship between perception and production has revealed inconclusive results. A still unresolved issue is whether the common representational system for perception and production is an innate endowment or a developmental achievement. An important question currently under discussion addresses the functional and temporal relationship between perception and production. The functional relationship describes the fact that one skill is a necessary prerequisite of the other skill; it entails the direction of causality whether a specific skill in, for example perception, is needed in order to develop the respective production skill or vice versa. The temporal relationship addresses the temporal order of development, whether one skill, dependent or independent of the other, develops earlier in time than the other. Three hypotheses have been put forward. Does the understanding of oneself as an agent precedes the understanding of others as agents (production first hypothesis), is the developmental course the reverse (perception first hypothesis), or do perception and action develop in parallel without one preceding or guiding the other (parallel development hypothesis).

The production first hypothesis suggests that infants come to understand others' actions based on their own skills in producing a respective action. Observed actions are simulated via one's own motor system, which limits infants' perception to human actions they are able to produce

(A. N. Meltzoff & Moore, 1994; Woodward, 1998). This hypothesis has its origin in constructivist theories based on the work of Piaget (1929). Recent research in support of this hypothesis has shown that the acquisition of a certain motor experience changes the perception of the same motoric act performed by somebody else (Cannon, Woodward, Gredebäck, von Hofsten, & Turek, 2012; Longo & Bertenthal, 2006; Melzer, Prinz, & Daum, 2012; Sommerville, Woodward, & Needham, 2005). Sommerville and colleagues (2005), for instance, trained one group of three-month-olds with sticky mittens before they were tested in a perception task while another group performed this action only after the action perception task. They found that only those infants with prior production experience were successful at perceiving the action as goal-directed in the perception task.

In contrast, the perception first hypothesis suggests that infants can make use of a variety of perceptual cues and their perception is not limited to their own action repertoire. According to this hypothesis, action perception is innately based on pre-wired interpretative schemas triggered by distinct action-related cues such as the self-propelledness of the agent, direction of the movement, efficiency of the action toward the goal and the presence of action effects (György Gergely & Csibra, 2003; Johnson, Tucker, Stiles, & Trauner, 1998; Leslie, 1994; Premack, 1990). This hypothesis has its origin in neonativist accounts (e.g., Leslie, 1988; Spelke, Breinlinger, Macomber, & Jacobson, 1992) suggesting that infants are born with an initial set of innate traits or behavioral rules. More recent search in support of this hypothesis has shown that infants are able to perceive actions before having the respective production ability (Biro & Leslie, 2007; Daum, Vuori, Prinz, & Aschersleben, 2009; Gergely, Nádasdy, Csibra, & Bíró, 1995; Hofer, Hauf, & Aschersleben, 2005; Hofstadter & Reznick, 1996). Daum and colleagues (2009), for instance, designed a preferential looking time study with expected and unexpected outcomes of a means-end action. The results showed that in the perception task, infants discriminated between the expected and the unexpected outcome of an observed means-end action, and that this perceptual ability was independent of their actual competence in producing means-end behavior in the action task.

Finally, the parallel development hypothesis suggests no dissociation between perception and production in development. Perception and production develop in parallel without one preceding or guiding the other. This hypothesis has its origin in the common-coding approach (Prinz, 1997) suggesting a bidirectional influence of production on perception and vice versa. Studies in support of this hypothesis have shown that perception and production are interrelated already in infancy (Daum et al., 2009; Kanakogi & Itakura, 2011). Kanakogi and Itakura (2011) compared gazing and grasping responses in 4- to 10-month old infants. The results show that the onsets of prediction and producing of grasps were synchronized and perception and production were interrelated.

Taken together these three hypotheses and the corresponding findings seem to be mutually exclusive. They draw contradictory answers to the question about the development of the relation of perception and production. This development can, however, vary depending on the perspective that is taken, for example, what age groups are targeted and which aspects of perception and production are investigated. When looking at previous studies assessing the functional relationship between perception and production, typically only one or only few age groups were tested. Often, one single age group is split into two groups, one with a specific production skill already established (e.g. the ability to perform a thumb opposite grasp, Daum et al., 2009) and one with this production skill still lacking. The infants' performance in a perception task is then evaluated. Dividing infants into a group of competent and a group of incompetent performers results in an artificial dichotomy that does not reflect the more graded nature of developmental transitions. Some infants will be categorized as poor graspers, although their grasping skill is already to some extent developed, some of them will be categorized as good graspers, although their grasping is only average. Using this procedure, only a small window of development is assessed and subtle differences in development are ignored what results in a skewed picture of the development of the respective skill.

When looking at different aspects of perception and production it is obvious that due to the limited motor repertoire early in life, a large number of studies investigated simple production skills that develop early mostly during the first year of life and for which the competent group of infants seems to have reached the ceiling of proficiency. However, it is likely that the investigated abilities have their onset before the point in time of the measurement of "no competence" and continue beyond the point in time of the measured "competence". Furthermore in everyday life, infants are rather confronted with complex multi-step actions as with well-defined simple actions of limited complexity.

Putting these different aspects together, we conclude that a general question about the developmental relationship of perception and production does not have a simple and one-dimensional answer but might result in different answers depending on the perspective taken.

The main research question of the present study addresses the developing relationship between perception and production. As outlined above, this question cannot be answered by investigating solely the functional relationship but only by additionally taking into account the temporal order. Which one comes first: perception of actions or production of actions? The temporal order can be examined by comparing the developmental trajectories. Doing so allows finding either that the improvement in perception precedes the improvement in production or that the improvement in production precedes the improvement in perception. We thus explored the long-term developmental course of perception and production with actions that involved familiar and novel skills. In a combined perception and production task children were tested over a broad age range beginning at the age of 12 months and continuing up to the age of 30 months in 6 months steps. We employed complex multi-step actions consisting of simple sub-action steps such as grasping and transporting objects in combination with more difficult tool-use action steps. We furthermore manipulated the familiarity of the actions involved by presenting actions the children are familiar with as well as novel actions, which the children were unlikely to have observed or performed before. Comparing familiar and novel actions with simple and more complex sub-action steps allows investigating the functional relationship between action production and action perception. To this end, special play boxes were created where several steps were necessary in order to achieve the overall goal of putting wooden blocks into the box. The procedure consisted of a perception and a production task: In the perception task, the children saw a movie of the respective action and their predictive eye movements were measured. In the production task, their imitation of the previously observed action was measured.

In the perception task, predictive eye movements towards the goal of the observed action were used as dependent measure. The logic behind this measure is that if a person performs an action, he or she will look at the goal of the action before it is completed. Such predictive gaze shifts are found not only during the performance of an own action but also during the observation of others who are engaged in functional, goal-directed actions both in adults (Flanagan & Johansson, 2003) and children (Cannon et al., 2012; Falck-Ytter, Gredebäck, & von Hofsten, 2006; Gredebäck, Stasiewicz, Falck-Ytter, Rosander, & von Hofsten, 2009; Rosander & von Hofsten, 2011). These predictive gaze shifts indicate that an observer has a built a representation of the goal of the observed action, and can predict the outcome of the action before it is actually completed. Furthermore the predictive eye movements are highly comparable to the production of an action as both involve the anticipation of a future state of the action (von Hofsten, 2004). Recent studies that have successfully combined a prediction paradigm with a production paradigm have so far reported a close link of perception and production being established early in life (Kanakogi & Itakura, 2011; Melzer et al., 2012).

In the production task, the children had to imitate the action that they had observed in the perception task. Imitation was chosen as production task as it involves not only the reproduction of an external result, but requires the integration of both a model's internal goal and the means chosen to achieve this goal. Imitation is thus an indicator of an observer's understanding of a model's intention (M. Tomasello, 1999) and provides information on how well the action was perceived and how well it was reproduced (Hommel, Müsseler, Aschersleben, & Prinz, 2001). Imitation has been widely used with children to show an understanding of the underlying intentionality (Carpenter, Akhtar, & Tomasello, 1998; A. Meltzoff, 1995), the rationality of the observed actions (G. Gergely, Bekkering, & Király, 2000; Zmyj, Daum, & Aschersleben, 2009), and the fidelity of copying (Flynn & Whiten, 2008).

Using action prediction and action imitation as dependent measures in a combined task allows not only to look at in isolation whether and how the very same action is imitated and whether action goals are predicted but to look at how these two are temporally and functionally interrelated over the course of development. From a general developmental perspective we expected that the ability to predict the action goals would increase with age (Falck-Ytter et al., 2006; Kanakogi & Itakura, 2011; Melzer et al., 2012) and likewise, that the proficiency in imitating the actions (Barr, Dowden, & Hayne, 1996; Elsner, Hauf, & Aschersleben, 2007; Zmyj et al., 2009) also increases with age. We furthermore expected that prediction and imitation are related. Concerning the temporal relationships, the three hypotheses introduced earlier make different predictions. The perception first hypothesis predicts that children are able to predict actions before they are able to imitate them (Daum et al., 2009; Hofer et al., 2005; Hofstadter & Reznick, 1996). The production first hypothesis predicts that children are able to predict only those actions that they are able to produce and they are not able to predict novel actions (Cannon et al., 2012; Longo & Bertenthal, 2006; Melzer et al., 2012; Sommerville et al., 2005). Finally, the parallel development hypothesis predicts that the developmental trajectories of perception and production develop in parallel. Concerning the functional relationship, we expected that the abilitity to predict the actions is correlated to the imitation of the actions (Kanakogi & Itakura, 2011; Melzer et al., 2012).

## 6.2 Methods

**Participants**

We analyzed data from 64 children (16 children of each age group: 12-month-olds: 9 girls, *M* = 12.5 months, *SD* = 0.28; 18-month-olds: 8 girls, *M* = 18.7, *SD* = 0.21; 24-month-olds: 8 girls, *M* = 24.7, *SD* = 0.21; 30-month-olds: 8 girls, *M* = 30.8, *SD* = 0.18). An additional 10 children were tested but excluded from the analysis due to lack of attention during the prediction task (12-month-olds: $n = 4$; 18-month-olds: $n = 4$, 24-month-olds: $n = 1$, 30-month-olds: $n = 1$). Additionally, 14 adults ($M = 23$, $SD = 4$) participated in the study. Adults served as a control group for the developmental trajectories. Using public birth records, we contacted parents and invited them to participate in the study after they provided informed consent. The children were all monolingual native German speakers and came from heterogeneous socioeconomic backgrounds. They received a present at the end of the session. The study was approved by the local ethics committee.

**Materials**

Children were presented with two *action conditions* (familiar action, novel action) with each action condition comprising two tasks (perception task, production task). For each action, a box, four blocks and a tool that were similar in shape and size were built. The overall goal of the actions was to put all four blocks into the box using the tool. The boxes were of equal size (original size in cm: 40 x 12 x 10 cm, visual angle of the video presentation at the infant's viewing distance of 60 cm: 16.1 x 8.1 x 6.5° visual angle), with four differently colored sections of equal size (10 x 20 cm, 6.5 x 12.8°). Each colored area contained a hole (diameter size = 50 mm, 2.0°) at the center. The box for the novel action condition had four additional plates (4 x 3 cm, 1.6 x 1,4°), which could be pulled in order to open the hole and move the blocks into the box. The blocks were wooden cylinders (diameter = 30 mm, height = 50 mm, 1.4 x 2.9°) colored green, brown, yellow or blue in the familiar action condition, and four wooden building blocks (35 x 35 mm, 1.5 x 1.5°) colored green, red, yellow or blue in the novel action condition, each matching the color of one respective box area. The tools were also of similar size (hammer in the familiar action condition: 21.5 x 6 cm, 5.7 x 2.4°, novel tool in the novel action condition: 21 x 4.5 cm, 6.2 x 1.9°). One end of the novel tool was covered with Velcro that could be placed on the plates of the novel action box in order to pull and open the hole. See Figure 1 for an overview of the materials and actions.

For each action condition, the actions were videotaped that were necessary to reach the goal: putting all blocks into the box using the tool. While the overall goal for both trials was the same, the actual movements and tools used in order to achieve the goal were different. In the familiar action condition, the blocks were put on the box in an ordinary manner and the tool used was a familiar hammer. In the novel action condition, the blocks were put on the box using an unfamiliar rotating movement and the tool as well as the way it had to be used (Velcro, pulling) was novel for children.

Each action comprised four *action sequences*, one sequence for each of the blocks, starting with the block that was closest to the acting person. Each action sequence consisted of four *action steps*: Step 1: The block was grasped. Step 2: The block was put on the box. Step 3: The tool was grasped. Step 4: The object was moved into the box using the tool. Prior to the action steps being presented, a verbal attention getter was presented ("I'll show you something"). The four actions sequences for each block were of equal length, but the different action steps varied in length due to natural variations of the movements; familiar action: 1) 1160 ms (17.2°/sec), 2) 1720 ms (10.9°/sec), 3) 1400 ms (14.3°/sec), 4) 1000 ms (18.9°/sec) and novel action: 1) 1160 ms (17.2°/sec), 2), 1960 ms (9.6°/sec), 3) 1400 ms (14.3°/sec), 4) 1400 ms (13.5°/sec). During the perception task, the children's eye movements were measured using a Tobii 1750 near infrared eye-tracker (Stockholm, Sweden; precision: 1°, accuracy: 0.5°, sampling rate: 50 Hz) with an infant add-on. A 9-point infant calibration was used. During calibration, a blue and white sphere expanded and contracted (extended diameter = 3.3°) in synchrony with a sound.

**Design and Procedure**

After a short familiarization and instruction phase in a playroom, the experimental session began in a test room. Children were presented with both action conditions (familiar action, novel action) in a counterbalanced order. For each action condition, the perception task was presented first, followed by the production task. In the perception task, children were presented with the videos of the respective familiar and novel actions for three times.

In the production task, the children were given the objects (blocks, tool, box) they had just seen on a table and had the opportunity to play with them. Neither the experimenter nor the parents interacted with the child during this production phase. The production phase finished when children successfully put all four blocks into the box, stopped acting on the objects or when they did not act on any of the objects for a maximum of 90 s.

The adults only participated in the perception task, since no variance in their imitation proficiency was expected within the present paradigm. After they were informed about the procedure, they gave informed consent and were led to the testing room.

**Data Analysis**

**Action prediction**. Two measures were calculated in the perception task: prediction frequency and number of perceived steps.

*Prediction Frequency*. To analyze the eye movement data, recorded gaze points from the right and left eye were averaged. If only data from one eye were available, this was used instead of the averaged data point. The goal areas of interest (AOI) were the blocks for action step 1 (AOIs: 5.27° x 3.86°), the colored area of the respective box for the action steps 2 and 4 (e.g., the AOI for the green blocks was the green area of the box, AOIs: 7.82° x 3.13°) and the tool for action step 3 (AOIs: 3.36° x 3.52°). The difference was calculated between the point in time the hand/tool/object entered the AOI of the respective action step and the point in time of the observer's first fixation (40 ms) within the same AOI. For the second action step of the novel action, the end of the action steps were calculated when the tool entered the AOI of the plate. This difference in time, henceforth called anticipation time was categorized in two subgroups: an anticipation time above zero indicated that the children's gaze arrived at the AOI prior to the hand/object/tool; this was classified as an "anticipation". In contrast, an anticipation time below zero indicated that gaze arrived at the AOI after the hand/object/tool; accordingly, this was classified as a "reaction". From the number of anticipations and reactions, the *prediction frequency* was calculated by dividing the number of anticipations by the sum of all gaze shifts (anticipations and reactions). In addition to the overall frequency of predictions, two additional frequencies were calculated for a) the non-tool action steps (frequency of action step 1 and 2) and b) the tool action steps (frequency of action step 3 and 4). The analysis of the prediction frequency as dependent measures was preferred over the mean anticipation time since the different action steps were of different length. Differences in anticipation times due to differences in the action timing were thus avoided.

*Number of perceived steps*. The number of perceived steps served as a measure of attention and was calculated as the sum of all steps that were "anticipations" or "reactions".

**Action imitation**. Infants' production of the observed action was coded from video by a trained observer. Two different measures were calculated: an imitation score and an emulation score.

*Imitation Score*. This score was used in order to examine which action steps were imitated and how often. The children's imitation behavior was coded from video for a fixed time of 90 seconds after the infant had first touched one of the objects involved. We measured the number of blocks that were grasped in accordance to action step 1, the number of blocks that were put onto the box (step 2), the number of times the tool was grasped or hold (step 3) and the number of times the tool was used (step 4). For each step the minimum number was 0 and the maximum was 4. The numbers of all action steps were accumulated as imitation score.

*Emulation Score*. The emulation score was additionally calculated in order to have an additional measure about the model's intention without taking into account the specific means chosen to achieve this goal. Furthermore, the duration needed to achieve the goal was taken into account (Wang, Fu, Zimmer, & Aschersleben, 2012). Differences in the duration reflect that some children are faster at putting the blocks into the box while others achieved the same goal but were much slower in their performance. The emulation score was calculated follows: the number of blocks that were successfully put into the box was divided by the total duration of the action production (start: touch of tool, box or object; end: fourth object in box or 90 s in the case that the action was not fully copied).

A second independent observer who was unfamiliar with the purpose of the study coded 25% of the sample to assess interrater reliability, which resulted in high agreement on all categories (imitation step 1: $\tau = .94$, imitation step 2: $\tau = .94$, imitation step 3: $\tau = .93$, imitation step 4: $\tau = .91$, emulation number: $\tau = .97$, emulation time: $\tau = .92$).

**Main Analyses**. Three major analyses were performed focusing on different aspects of the present study but without any bias towards on of the hypotheses. The first analysis focused on the similarities between prediction and imitation/emulation by calculating correlations between those scores. The second analysis deals with developmental trajectories as analyzed with ANOVAs and post-hoc comparisons between the different age groups. Here we were interested in differences in the trajectories of prediction and imitation/emulation. In the third analysis we looked more specifically at differences between the familiar and the novel action conditions and at differences between non-tool and tool-use action sequences. This was done using t-tests in the different age groups.

## 6.3 Results

Preliminary analyses showed no effect of sex, order of conditions and number of perceived action steps (all $p > .34$). Accordingly, data was collapsed across these factors.

**Interrelation Between Prediction and Imitation**. In the first analysis, we were interested in whether the ability to predict the goal of an observed action was correlated with the ability to imitate the same action. Therefore partial correlations were calculated separately for the familiar and the novel action between the prediction frequency and the imitation and the emulation score were calculated, controlling for age.

*Familiar Action Condition*. In the familiar action condition, prediction frequency was highly correlated with the imitation score, $r(55) = .42$, $p = .002$ and tended to correlate with the emulation score, $r(55) = .25$, $p = .06$. Due to the fact that a substantial number of the older children (20%) reached ceiling in the imitation score (i.e. reached the maximum score of 16) which could have biased the significant correlation with the imitation score, we additionally run a correlation with only those children who were not yet at ceiling and had a score below 16. In line with the previous results, the prediction frequency was still highly correlated with the imitation score $r(44) = .47$, $p = .001$.

*Novel Action Condition*. In the novel action condition, prediction frequency was correlated with the emulation score, $r(56) = .28$, $p = .031$, but not with the imitation score $r(56) = .09$, $p = .50$. Due to the fact that many younger children showed a floor effect in their emulation score (i.e. score of 0; 44%), we again run a second correlation with a sub set of the participants. This time, we selected only those who had an emulation score above zero. The prediction frequency was found to correlate with the emulation score comparably if not even stronger, $r(31) = .42$, $p = .015$.

The analyses in this section showed a close interrelation between the children's ability to predict the goal of an action and their ability to imitate and emulate the very same action. This speaks for an interrelation between perception and production.

**Developmental trajectories**. The main question in this analysis was whether the abilities to predict and imitate the complex action depend on age. The dependencies on age were then compared between prediction and imitation.

We thus run separate ANOVAs on all dependent measures with age (12, 18, 24, 30) as between-subject factor and conducted Bonferroni-corrected post-hoc comparisons between age groups. Due to the large number of dependent measures and pairwise age group couplings we report the results of the statistical analyses for the perception task in Table 1 and for the production task in Table 2, for an easier visualization of the results; the developmental trajectories are furthermore depicted in Figure 2.

In all dependent measures, performance significantly increased over age, however the developmental trajectories between prediction and imitation differed between conditions. In the familiar action the main increase in performance in the perception task took place between 12 and 18 months, that is, the prediction frequencies of the 18-month-olds reached a plateau and did not differ from the frequencies of the 24- or 30-month-olds. In the imitation and emulation in contrast the main increase took place around 6 months later between 18 and 24 months of age. In contrast, in the novel action, prediction and imitation seem to develop in parallel. In both measures the main increase occurred between 18 and 24 months of age.

In summary, this analysis showed that the prediction of familiar actions reached a plateau earlier as the imitation of familiar actions, which was not the case in the novel actions. This can be interpreted as an earlier development in the prediction of familiar actions compared to the imitation/emulation and a simultaneous development of the prediction and imitation/emulation of novel actions.

**Familiar and Novel Actions**. The third analysis looked at differences between familiar and novel actions and action steps. This first question was: Do children differentially process familiar and novel multi-step actions, and if so, in which dependent measures and at what age? To test this, we compared the prediction frequencies, the imitation and the emulation scores of the familiar action and the unfamiliar action condition in each age group separately using paired-sample t-tests. The results are depicted in Table 3 and the developmental trajectories are depicted in Figure 2A. In general, the prediction frequencies did not differ between the familiar and novel actions. The only difference that we found in the 18-month-olds might be caused by a slower increase in performance of the novel actions as compared to the familiar actions in the 12- to 18-month-olds. This possible explanation was investigated using a repeated-measures ANOVA with action condition (familiar action, novel action) as within-subjects factor and age (12, 18) as between-subjects factor. This analysis revealed in fact a significant interaction between action condition and age, $F(1, 30) = 4.48$, $p = .043$, showing that the increase of the prediction frequency was faster in the familiar action than in the novel action. In other words, children were proficient at predicting the familiar actions already at the age of 18 months while the prediction of novel actions was proficient 6 months later at the age of 24 months. Children at the age of 24 and 30 months did not differentiate between familiar and novel actions in their prediction frequency, probably because they were already at ceiling.

In a next step, we analyzed the data of the adults. Results showed that adults showed a more frequent action prediction in the familiar action compared to the novel action. This finding suggests a further differentiation of prediction later in development.

When looking at the imitation and emulation data, we found that children differentiated between the familiar and novel action in their own production. Twelve- to 24-month-olds were better at imitating familiar actions than novel actions (30-month-olds were already at ceiling) and 18- to 30-month-olds were better at emulating familiar actions as compared to novel actions (12-month-olds were not yet very successful).

In a next step of the second analysis we investigated differences between tool and non-tool steps. The second question was: Do children differentiate between non-tool and tool steps and if so, in which dependent measures and at what age? For this, we compared prediction frequency and imitation score of the non-tool action steps with the tool action steps in each age group separately using paired-sample t-tests. The emulation score was not analyzed in this section as it was calculated only for the whole emulation but not for separate parts. The results are depicted in Table 4 and the developmental trajectories for the anticipation are depicted in Figure 2B and for the imitation in Figure 2C.

The prediction frequency of the younger children (12 to 24 months) did not differ between the non-tool and the tool action steps, neither for the familiar nor the novel action. In contrast, at the age of 30 months, the prediction frequency was higher in non-tool action steps compared to tool action steps. When looking at the results of the adult participants, the differentiation between non-tool and tool steps only occurred in the novel action but not in the familiar action. With respect to the imitation score, children of all age groups were better at imitating the non-tool action steps of the familiar action; furthermore, the 18- to 30-month-olds were better at imitating the non-tool action steps of the novel action.

In summary, with respect to the prediction and imitation/emulation of familiar and novel actions, the present results showed that in their prediction children at the age of 18 months and adults differentiated between familiar and novel actions, whereas they did so in their imitation already at 12 months and in emulation up to 30 months. With respect to the prediction and imitation of the non-tool and tool action steps, the presents results showed that children at the age of 30 months and adults differentiated between non-tool and tool action steps, whereas they did so in their imitation between 18 and 30 months. This speaks for different developmental trajectories of perception and production in favor of production.

## 6.4 Discussion

The aim of the present study was to shed light on the seemingly conflicting findings of previous studies on the development of the interrelation between action perception and action production. To this end we tested the development of children's perception and production over a wide age range using more ecologically valid familiar and novel multistep actions. We analyzed the prediction frequencies in the perception task and the imitation / emulation scores in the production task. In addition to investigating the children's performance at the level of whole actions, this was also done separately for tool and non-tool action steps.

The three major findings of the present study can be summarized as follows. First, the ability to predict an action goal was highly correlated to the ability to imitate the observed action independent of age. This suggests that perception and production develop in close interrelation and speaks for the parallel development hypothesis and for a common representation between perception and production (Prinz, 1997).

Second, in familiar actions prediction preceded imitation/emulation whereas in the novel action, prediction and imitation/emulation developed simultaneously. The former finding in the familiar actions speaks for the perception first hypothesis, while the latter finding in the novel actions speaks for the parallel development hypothesis. Third, while children imitated the familiar action better than the novel action up to 24 months their predictions did not differ in the age groups, expect at 18 months (and in adult age). A similar result was found when looking at the action steps separately. While children imitated the non-tool action steps better then the tool-action steps their predictions of the non-tool and tool action steps did not differ between 12 and 24 months of age. Only at 30 months of age they showed a faster prediction of the non-tool action steps. The prediction findings in the younger ages speak for the perception first hypothesis and imply the involvement of an inferential processing of others' actions that are independent of one's own production skills (György Gergely & Csibra, 2003; Johnson et al., 1998; Leslie, 1994; Premack, 1990). The prediction findings in the 30-month-olds and the imitation findings speak for the production first hypothesis. In the familiar action children might draw on their own experience of producing the respective actions when imitating them. This was not possible in the case of novel actions.

At first glance, these findings seem to make the complicated picture even more complicated. In order to counteract this first impression and to get a clearer picture we will now integrate the results into a coherent framework.

**Integration of the findings**

For a start, it is helpful to look at the results for the different age groups in isolation. When only looking at the results of the younger two age groups (12-18 months), the present results support a perception first hypothesis: Children's action prediction reaches a plateau of competence at an earlier age than their action imitation. In contrast, when looking at the results of the older two age groups (24-30 months), the present results support the production first hypothesis. Children differentiate in the prediction task between non-tool and tool action steps in favor of the simpler non-tool action steps only after having acquired a robust production competence. Finally, over all age groups, the strong correlation between action prediction and imitation suggests that both perception and action develop in parallel and share a common representation (Prinz, 1997).

The obvious question now is: How does this all fit together within one coherent framework? When looking at the general pattern of results, it is likely that all three accounts are present at some points in development. In the present study infants were able to predict the goals of ongoing novel actions. Accordingly, children are able to use a set of inferential tools to interpret ongoing actions in their surrounding (self-propelledness, equifinality, biological motion, Biro & Leslie, 2007). Based on this level of interpretation of others actions these actions can then be implemented into one's own production repertoire (Michael Tomasello, Kruger, & Ratner, 1993). In the present study, the children were able to imitate both familiar and novel actions. Through the acquisition of a new action production skill, a respective action representation is either newly built or updated. As a consequence, this updated representation is then used as the basis for the subsequent perception of this action and results in a modified interpretation (Calvo-Merino, Glaser, Passingham, & Haggard, 2005; Sommerville et al., 2005). We found a differentiation between the prediction of familiar and novel actions in favor of familiar action in 18 months and in adults and a differentiation between tool and non-tool action steps in favor of the non-tool steps at 30 months and in adults. This suggests that the more experienced children are the better they can predict those actions. Summarizing these different developmental trajectories results in the following relation between perception and production: The correlation of perception and production over all age groups shows that perception and action are two components that share a common representation (Jeannerod, 2001; Prinz, 1997; Rizzolatti & Craighero, 2004). Furthermore, the findings that at young age, perception seems to lead production and at older age, production seems to lead perception, suggests that both components are influential to the respective other one in development. Once one component is enriched with experience this leads to modified preconditions for the other component. This other component then might adapt to the new proficiency of the other component within itself, which in turn might lead to a further adaption in the first component. It might well be that the developmental trajectories of perception and production differ and that they influence each other. However, the present data demonstrates that the pattern of development is not unidirectional with one component always leading the other. The functional and temporal relationship between perception and production depends on which age groups are investigated and which aspects of perception and production are looked at. By investigating the temporal relationship through long-term developmental trajectories both temporal orders were found: perception leading production and production improving perception. This suggests that the two components are integrated in a dynamic system where the enrichment of one component entails the development of the other component and vice versa (Thelen & Smith, 2007). This idea of circularity or bidirectional influence is strongly supported by findings in adults. Action perception influences action production (Brass, Bekkering, & Prinz, 2001; Brass, Bekkering, Wohlschläger, & Prinz, 2000; Craighero, Bello, Fadiga, & Rizzolatti, 2002; Kilner, Paulignan, & Blakemore, 2003; Stürmer, Aschersleben, & Prinz, 2000) and vice versa, action production influences action perception (Hamilton, Wolpert, & Frith, 2004; Jacobs & Shiffrar, 2005; Miall et al., 2006; Wühr & Müsseler, 2001).

In summary, the findings revealed multiple developmental trajectories of perception and production within a single paradigm and thus show that the overarching question about the development of the temporal and functional relationship between perception and production cannot be answered by one simple answer. In contrast, the answer depends on which aspects are focused on. The answers of our study showed a reciprocal development of perception and production with each of the two influencing the respective other one.

## References


Barr, R., Dowden, A., & Hayne, H. (1996). Developmental changes in deferred imitation by 6- to 24-month-old infants. *Infant Behavior & Development*, *19*, 159–170.

Biro, S., & Leslie, A. M. (2007). Infants' perception of goal-directed actions: development through cue-based bootstrapping. *Developmental Science*, *10*(3), 379–398. doi:10.1111/j.1467-7687.2006.00544.x

Brass, M., Bekkering, H., & Prinz, W. (2001). Movement observation affects movement execution in a simple response task. *Acta Psychologica*, *106*(1–2), 3–22. doi:10.1016/S0001-6918(00)00024-X

Brass, M., Bekkering, H., Wohlschläger, A., & Prinz, W. (2000). Compatibility between Observed and Executed Finger Movements: Comparing Symbolic, Spatial, and Imitative Cues. *Brain and Cognition*, *44*(2), 124–143. doi:10.1006/brcg.2000.1225

Calvo-Merino, B., Glaser, D. E., Passingham, R. E., & Haggard, P. (2005). Action Observation and Acquired Motor Skills: An fMRI Study with Expert Dancers. *Cerebral Cortex*, *15*, 1243–1249.

Cannon, E. N., Woodward, A. L., Gredebäck, G., von Hofsten, C., & Turek, C. (2012). Action production influences 12-month-old infants' attention to others' actions. *Developmental Science*, *15*, 35–42. doi:10.1111/j.1467-7687.2011.01095.x

Carpenter, M., Akhtar, N., & Tomasello, M. (1998). Fourteen- through 18-month-old infants differentially imitate intentional and accidental actions. *Infant Behavior & Development*, *21*, 315–330.

Craighero, L., Bello, A., Fadiga, L., & Rizzolatti, G. (2002). Hand action preparation influences the responses to hand pictures. *Neuropsychologia*, *40*(5), 492–502. doi:10.1016/S0028-3932(01)00134-8

Daum, M. M., Vuori, M. T., Prinz, W., & Aschersleben, G. (2009). Inferring the size of a goal object from an actor's grasping movement in 6- and 9-month-old infants. *Developmental science*, *12*(6), 854–862. doi:10.1111/j.1467-7687.2009.00831.x

Elsner, B., Hauf, P., & Aschersleben, G. (2007). Imitating step by step: a detailed analysis of 9- to 15-month-olds' reproduction of a three-step action sequence. *Infant Behavior & Development*, *30*, 325–335.

Falck-Ytter, T., Gredebäck, G., & von Hofsten, C. (2006). Infants predict other people's action goals. *Nature Neuroscience*, *9*, 878–879.

Flanagan, J. R., & Johansson, R. S. (2003). Action plans used in action observation. *Nature*, *424*, 769–771.

Flynn, E., & Whiten, A. (2008). Cultural transmission of tool use in young children: A diffusion chain study. *Social Development*, *17*, 699–718.

Gergely, G., Bekkering, H., & Király, I. (2000). Developmental psychology: Rational imitation in preverbal infants. *Nature*, *415*, 755.

Gergely, György, & Csibra, G. (2003). Teleological reasoning in infancy: the naïve theory of rational action. *Trends in Cognitive Sciences*, *7*(7), 287–292. doi:10.1016/S1364-6613(03)00128-1

Gergely, György, Nádasdy, Z., Csibra, G., & Bíró, S. (1995). Taking the intentional stance at 12 months of age. *Cognition*, *56*(2), 165–193. doi:10.1016/0010-0277(95)00661-H

Gredebäck, G., Stasiewicz, D., Falck-Ytter, T., Rosander, K., & von Hofsten, C. (2009). Action type and goal type modulate goal-directed gaze shifts in 14-month-old infants. *Developmental Psychology*, *45*, 1190–1194.

Hamilton, A., Wolpert, D., & Frith, U. (2004). Your Own Action Influences How You Perceive Another Person's Action. *Current Biology*, *14*(6), 493–498. doi:10.1016/j.cub.2004.03.007

Hofer, T., Hauf, P., & Aschersleben, G. (2005). Infant's perception of goal-directed actions performed by a mechanical device. *Infant Behavior and Development*, *28*(4), 466–480. doi:10.1016/j.infbeh.2005.04.002

Hofstadter, M., & Reznick, J. S. (1996). Response Modality Affects Human Infant Delayed-Response Performance. *Child Development*, *67*(2), 646–658. doi:10.1111/j.1467-8624.1996.tb01757.x

Hommel, B., Müsseler, J., Aschersleben, G., & Prinz, W. (2001). The theory of event coding (tec): A framework for perception and action planning. *Behavioral and Brain Sciences*, *24*, 849–937.

Jacobs, A., & Shiffrar, M. (2005). Walking Perception by Walking Observers. *Journal of Experimental Psychology: Human Perception and Performance*, *31*(1), 157–169. doi:10.1037/0096-1523.31.1.157

Jeannerod, M. (2001). Neural simulation of action: A unifying mechanism for motor cognition. *NeuroImage*, *14*, S103–S109.

Johnson, M. H., Tucker, L. A., Stiles, J., & Trauner, D. (1998). Visual attention in infants with perinatal brain damage: Evidence of the importance of anterior lesions. *Developmental Science*, *1*(1), 53–58. doi:10.1111/1467-7687.00012

Kanakogi, Y., & Itakura, S. (2011). Developmental correspondence between action prediction and motor ability in early infancy. *Nature Communications*, *2*, 1–6.

Kilner, J. ., Paulignan, Y., & Blakemore, S. . (2003). An Interference Effect of Observed Biological Movement on Action. *Current Biology*, *13*(6), 522–525. doi:10.1016/S0960-9822(03)00165-9

Leslie, A. M. (1988). The necessity of illusion: Perception and thought in infancy. *Thought without language*, A Fyssen Foundation symposium. (pp. 185–210). New York, NY, US: Clarendon Press/Oxford University Press.

Leslie, A. M. (1994). ToMM, ToBy, and agency: Core architecture and domain specificity. In L. A. Hirschfeld & S. A. Gelman (Eds.), *Domain-specificity in cognition and culture*. New York: Cambridge University Press.

Longo, M. R., & Bertenthal, B. I. (2006). Common coding of observations and execution of action in 9-month-old infants. *Infancy*, *10*, 43–59.

Meltzoff, A. (1995). Understanding the intentions of others. *Developmental Psychology*, *31*, 838–850.

Meltzoff, A. N., & Moore, K. M. (1994). Imitation, memory, and the representation of persons. *Infant Behavior and Development*, *17*(1), 83–99. doi:10.1016/0163-6383(94)90024-8

Melzer, A., Prinz, W., & Daum, M. M. (2012). Production and perception of contralateral reaching: A close link by 12 months of age. *Infant behavior & development*, *35*(3), 570–579. doi:10.1016/j.infbeh.2012.05.003

Miall, R. C., Stanley, J., Todhunter, S., Levick, C., Lindo, S., & Miall, J. D. (2006). Performing hand actions assists the visual discrimination of similar hand postures. *Neuropsychologia*, *44*(6), 966–976. doi:10.1016/j.neuropsychologia.2005.09.006

Piaget, J. (1929). *The Child's Conception of the World*. Rowman & Littlefield.

Premack, D. (1990). The infant's theory of self-propelled objects. *Cognition*, *36*(1), 1–16. doi:10.1016/0010-0277(90)90051-K

Prinz, W. (1997). Perception and action planning. *European Journal of Cognitive Psychology*, *9*, 129–154.

Rizzolatti, G., & Craighero, L. (2004). The Mirror-Neuron System. *Annual Review of Neuroscience*, *27*, 169–92.

Rosander, K., & von Hofsten, C. (2011). Predictive gaze shifts elicited during observed and performed actions in 10-month-old infants and adults. *Neuropsychologia*, *49*(10), 2911–2917. doi:10.1016/j.neuropsychologia.2011.06.018

Sommerville, J. A., Woodward, A. L., & Needham, A. (2005). Action experience alters 3-month-old infants' perception of others' actions. *Cognition*, *96*, B1–B11.

Spelke, E. S., Breinlinger, K., Macomber, J., & Jacobson, K. (1992). Origins of knowledge. *Psychological Review*, *99*(4), 605–632. doi:10.1037/0033-295X.99.4.605

Stürmer, B., Aschersleben, G., & Prinz, W. (2000). Correspondence effects with manual gestures and postures: A study of imitation. *Journal of Experimental Psychology: Human Perception and Performance*, *26*(6), 1746–1759. doi:10.1037/0096-1523.26.6.1746

Thelen, E., & Smith, L. B. (2007). Dynamic Systems Theories. *Handbook of Child Psychology*. John Wiley & Sons, Inc. Retrieved from http://onlinelibrary.wiley.com/doi/10.1002/9780470147658.chpsy0106/abstract

Tomasello, M. (1999). *The cultural origins of human cognition*. Cambrigde, MA: Harvard University Press.

Tomasello, Michael, Kruger, A. C., & Ratner, H. H. (1993). Cultural learning. *Behavioral and Brain Sciences*, *16*(03), 495–511. doi:10.1017/S0140525X0003123X

von Hofsten, C. (2004). An action perspective on motor development. *Trends in Cognitive Sciences*, *8*(6), 266–272. doi:10.1016/j.tics.2004.04.002

Wang, L., Fu, X., Zimmer, H. D., & Aschersleben, G. (2012). Familiarity and complexity modulate the way children imitate tool-use actions: A cross-cultural study. *Journal of Cognitive Psychology*, *24*(2), 221–228. doi:10.1080/20445911.2011.617300

Woodward, A. L. (1998). Infants selectively encode the goal object of an actor's reach. *Cognition*, *69*, 1–34.

Wühr, P., & Müsseler, J. (2001). Time course of the blindness to response-compatible stimuli. *Journal of Experimental Psychology: Human Perception and Performance*, *27*(5), 1260–1270. doi:10.1037/0096-1523.27.5.1260

Zmyj, N., Daum, M. M., & Aschersleben, G. (2009). The Development of Rational Imitation in 9- and 12-Month-Old Infants. *Infancy*, *14*, 131–141.

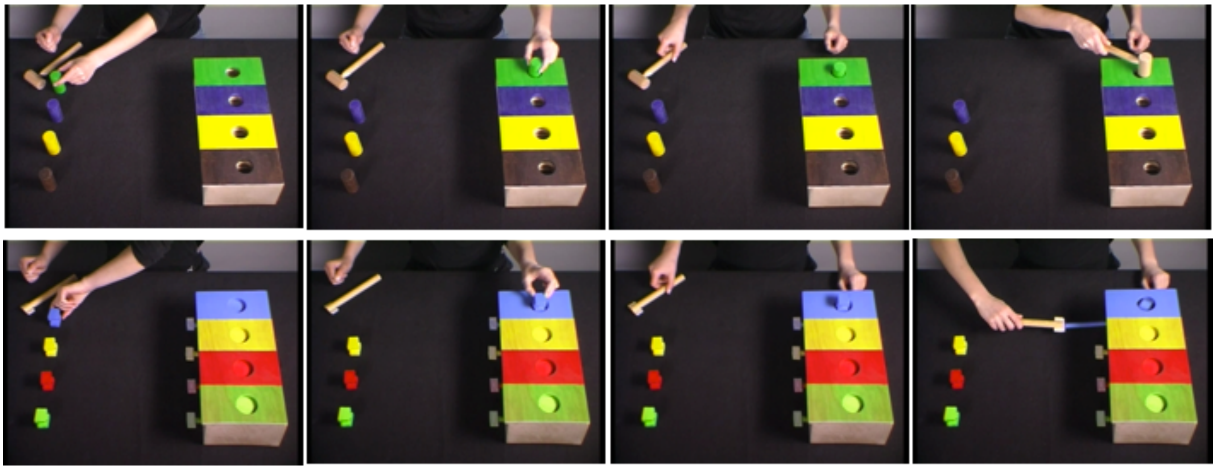

Figure 1. Stimulus Material used for the familiar action (upper row) and the novel action (lower row). Each key frame depicts one of the steps: Step 1 grasping of the block, Step 2 putting the block onto the box, Step 3 grasping the tool and Step 4 using the tool to put the block into the box.

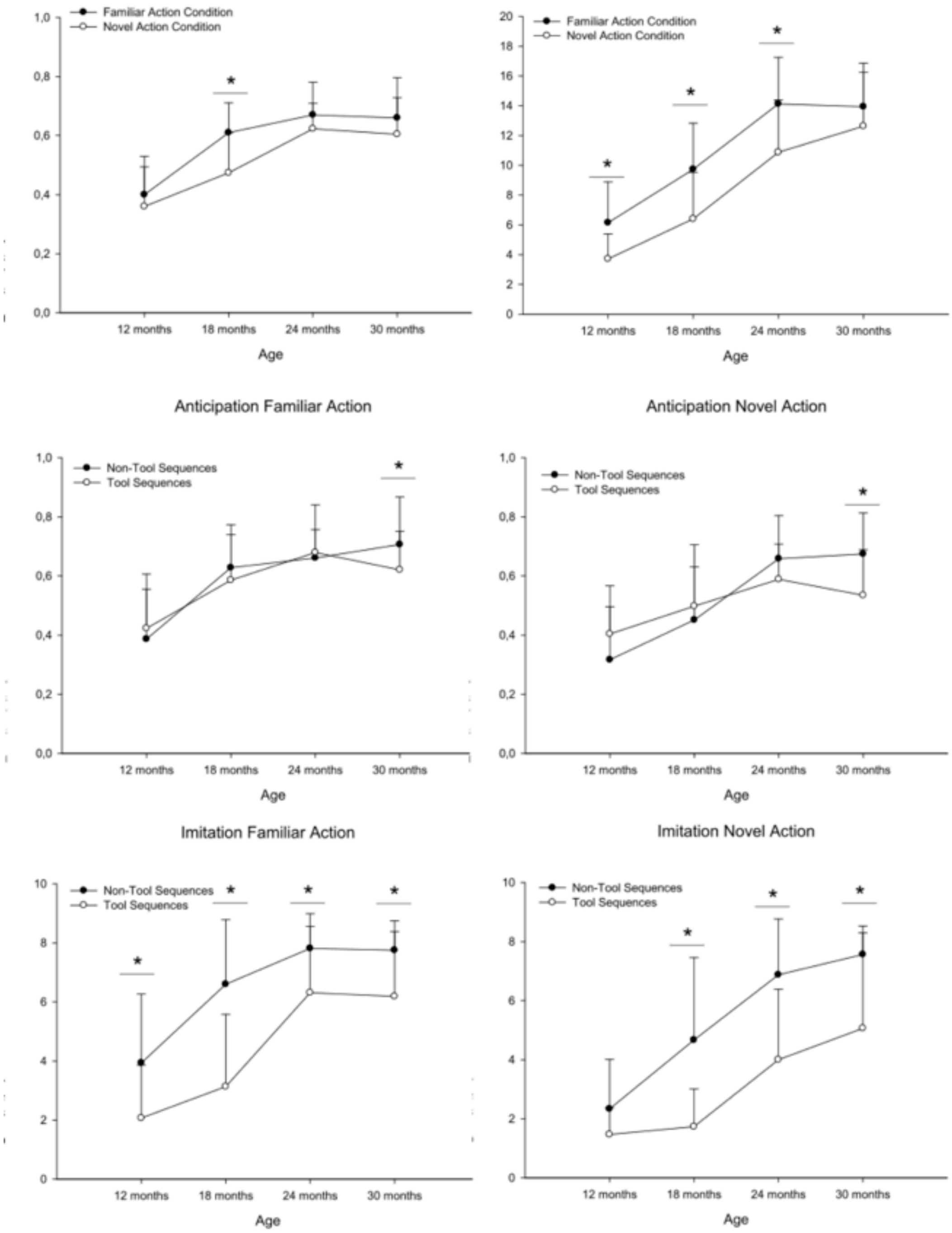


Figure 2: Results of the perception and imitation task: A depicts the anticipation and imitation results for the familiar and the novel action condition, B depicts the anticipation results for the non-tool and the tool sequences and C depicts the imitation results for the non-tool and the tool sequences.

| Dependent Measure | ANOVA | | 12-18 | 12-24 | 12-30 | 18-24 | 18-30 | 24-30 |
|---|---|---|---|---|---|---|---|---|
| | F | p | p | p | p | p | p | p |
| Anticipation Familiar Action | 16.67 | < .001 | < .001 | < .001 | < .001 | --- | --- | --- |
| Anticipation Non-Tool Steps | 12.35 | < .001 | .001 | < .001 | < .001 | --- | --- | --- |
| Anticipation Tool Steps | 9.16 | < .001 | .014 | < .001 | .002 | --- | --- | --- |
| Anticipation Novel Action | 16.27 | < .001 | --- | < .001 | < .001 | .006 | .023 | --- |
| Anticipation Non-Tool Steps | 18.05 | < .001 | --- | < .001 | < .001 | .004 | .002 | --- |
| Anticipation Tool Steps | 3.59 | .019 | --- | .014 | --- | --- | --- | --- |

Table 1: ANOVA statistics (columns 2 and 3) and Bonferroni corrected t tests (columns 4 - 9) for the main effects of Age. For each combination of age pair and dependent anticipation measure for which a significant difference was found, the p value for the post hoc test is given. Where no value is given the groups did not differ significantly.

| Dependent Measure | ANOVA F | p | 12-18 p | 12-24 p | 12-30 p | 18-24 p | 18-30 p | 24-30 p |
|---|---|---|---|---|---|---|---|---|
| Emulation Familiar Action | 15.49 | < .001 | --- | < .001 | < .001 | .01 | .001 | --- |
| Imitation Familiar Action | 26.09 | < .001 | .007 | < .001 | < .001 | .001 | .001 | --- |
| Imitation Non-Tool Steps | 17.41 | < .001 | < .001 | < .001 | < .001 | --- | --- | --- |
| Imitation Tool Steps | 13.46 | < .001 | --- | < .001 | < .001 | .002 | .003 | --- |
| Emulation Novel Action | 11.29 | < .001 | --- | < .001 | <.001 | .001 | .012 | --- |
| Imitation Novel Action | 26.35 | < .001 | --- | < .001 | < .001 | .001 | < .001 | --- |
| Imitation Non-Tool Steps | 23.12 | < .001 | .01 | < .001 | < .001 | .014 | .001 | --- |
| Imitation Tool Steps | 9.93 | < .001 | --- | .013 | < .001 | .033 | < .001 | --- |

Table 2: ANOVA statistics (columns 2 and 3) and Bonferroni corrected t tests (columns 4 - 9) for the main effects of Age. For each combination of age pair and dependent imitation measure for which a significant difference was found, the p value for the post hoc test is given. Where no value is given the groups did not differ significantly.

| Age Group | Anticipation | | Imitation | | Emulation | |
|---|---|---|---|---|---|---|
| df = 15 | t | p | t | p | t | p |
| 12 months | 1.73 | .102 | 3.39 | .005* | 1.87 | .086 |
| 18 months | 4.03 | .001* | 3.03 | .009* | 2.84 | .015* |
| 24 months | 1.27 | .218 | 2.56 | .022* | 2.31 | .035* |
| 30 months | 1.53 | .143 | 1.61 | .132 | 3.45 | .004* |
| Adults (df = 13) | 4.29 | .001* | | | | |

Table 3: Paired-sample t-tests statistics that tested for a difference between the familiar action and the novel action condition in the four age groups. In all cases where a significant difference was found the corresponding dependent measure of the familiar action condition received higher values than the novel action condition.

| Age Group | Familiar Action | | | | Novel Action | | | |
|---|---|---|---|---|---|---|---|---|
| | Anticipation | | Imitation | | Anticipation | | Imitation | |
| df = 15 | t | p | t | p | t | p | t | p |
| 12 months | -0.58 | .566 | 2.27 | .039* | -1.65 | .119 | 1.57 | .138 |
| 18 months | .758 | .460 | 3.87 | .002* | -0.67 | .461 | 3.77 | .002* |
| 24 months | -0.53 | .609 | 2.53 | .023* | 1.37 | .189 | 4.60 | <.001* |
| 30 months | 3.16 | .006* | 3.57 | .003* | 3.53 | .003* | 3.21 | .006* |
| Adults (df = 13) | -.1 | .922 | | | 3.62 | .004* | | |

Table 4: Paired-sample t-tests statistics that tested for a difference between the non-tool and tool steps in the four age groups. In all cases where a significant difference was found the corresponding dependent measure of the non-tool steps received higher values than the tool steps.

# 7 Productive Verbs Facilitate Action Prediction in Toddlers

Abstract

Children can represent events in our every-day life in both non-linguistic and linguistic representations. We aimed at investigating wheter non-linguistic representations are changed once children acquire their linguistic counterparts. In the present study, we thus explored whether and how language changes the perception of simple means-end actions using an eye-tracking paradigm. Children between 12 and 24 months of age heard a sentence containing a verb and subsequently watched an action video. Results show an interfering influence of language on action perception at 12 months and a facilitating influence at 24 months. However, this was only the case for verbs that are already in the toddlers' productive vocabulary but not for those that are acquired later. Taken together, the results suggest that a communication between non-linguistic and linguistic representations starts early and develops in the second year of life, while the successful facilitatory influence depends on the productive repertoire of the language in question.

## 7.1 Introduction

Language acquisition is one of the great milestones in human development. As a means of communication it enables children to talk about wishes, perceived events or plans for the future. While we know that language builds on the non-verbal understanding of the world, it is still an open debate how language influences our perception of the world. Here, we investigated whether and how language changes young children's perception of simple means-end actions.

Events in our every-day life can be represented in different modes of representation (Bruner, 1964). Infants are able to form non-linguistic representations about objects and events (enactive and iconic modes, Bruner, 1964). Within the social domain, infants are able to represent the goal of others actions by the middle of their first year of life (e.g. Biro & Leslie, 2007; Falck-Ytter, Gredebäck, & von Hofsten, 2006; Gergely, Nádasdy, Csibra, & Bíró, 1995; Woodward, 1998). Around half a year later, they start to acquire language and can thus represent objects and events in an additional linguistic representation (symbolic mode, Bruner, 1964). At around 12 months of age, infants start to produce their first words and reach the 50-words level at 18 months of age. While different authors claim a developmental order of these representations with non-linguistic representations being first and linguistic representations coming next (Bruner, 1964; Kosslyn, 1978; Piaget & Inhelder, 1966; Werner, 1926), nothing is said about whether infants' early non-linguistic representations are influenced as they enter the linguistic representational system. In the next paragraphs we will review studies that suggest an interrelation between linguistic and non-linguistic representations.

A number of studies showed that the motor development in the first year of life goes hand in hand with the beginning of sound production and word production. For example, the increase of rhythmic arm gestures is related to the beginning of rhythmic sound production such as reduplicated babbling (Thelen, 1979). This is not surprising as sound production itself is a motor act. Later on, motor skills like object displacement (Lifter & Bloom, 1989) and recognitory gestures (i.e., actions carried out on an object to depict its function, Capirci, Contaldo, Caselli, & Volterra, 2005) influence the infants's first productive words. Names of objects that are easy to manipulate enter the productive vocabulary repertoire first (Nelson, 1973; Rodgon, Jankowski, & Alenskas, 1977), and additionally, communicative pointing and the ability for joint attention are precursors to linguistic abilities (Bates, Benigni, Bretherton, Camaioni, & Volterra, 1979; Carpenter, Akhtar, & Tomasello, 1998). Accordingly, action skills at a preverbal age are longitudinally related to linguistic skills at a later age.

Furthermore, linguistic information modulates the perception of non-verbal tasks. Between the ages of 6 and 12 months, word phrases facilitate category formation (Balaban & Waxman, 1997; Fulkerson & Waxman, 2007). Infants who heared one label for two distinct objects formed one category whereas infants who heard two distinct labels for those two objects formed two categories (Fulkerson & Waxman, 2007). These results were extended by a further condition in which infants at the age of 10 months heard two labels that were uncorrelated to the visual category. In this case, infants did not form any category (Plunkett, Hu, & Cohen, 2008). And even beyond the preverbal months, language can influence the way we perceive objects. Generalizations about object properties are made by 14 and 22 months of age when accompanied by the same linguistic stimuli (Graham & Kilbreath, 2007). Taken together these results show that labels have a strong impact on the categorization of objects in preverbal and verbal months.

So far, the impact of language on action has primarily been investigated in the domain of non-social cognition, that is mainly object perception. But what about action perception; in everyday life infants and children are continuosly confronted with social interactions and need to understand what others do. The few studies that have focused on the interrleation of language and action suggest that language also impacts on the children's perception of other's actions. The presence or absence of communicative speech has a substantial influence on infants' performance in an A-not-B error task at the age of 10 months (Topál, Gergely, Miklósi, Erdöhegyi, & Csibra, 2008) and on the perception of pointing gestures at the age of 12 months (Daum, Ulber, & Gredebäck, in press). Given thesese general influences the question arises whether not only language general but also language specific impacts exist. In other words: Is the perception of a specific action altered after having a the specific linguistic representation of the action? Results from adults suggest that action perception is facilitated after reading a congruent verb (Springer & Prinz, 2010). A similar result has been found in ten-year-old children who were able to make online predicitons of verbal goals, that is patients, after hearing a label (Nation, Marshall, & Altmann, 2003). In this study, when hearing a sentence like "The boy eats a big cake", skilled comprehenders shifted their gaze towards a picture of a cake before the word „cake" was uttered. The question remains about the interrelation between non-linguistic anc linguistic representations at the onset of language acquisition. Are specific linguistic and non-linguistic representations interrelated already at the beginning? And if so, how do linguistic representations influence non-linguistic representations?

Two key research aims related to these general questions were guiding the present research: 1) We aimed at locating the point of time in development when specific linguistic information do change the perception of an action as found in adults (Springer & Prinz, 2010). This point of time might be found already at the onset of language acquisition or only later, at a more advanced stage of language production. 2) We aimed at determining the prerequisites for the interrelation between linguistic and non-linguistic representations. Either, the link between the two representational formats is non-specific and depends primarily on the factor age or this link depends on the specific knowledge for each specific item in question.

To address these issues, we used a combination of the paradigms by Springer and Prinz (2010) and Nation, Marshall, and Altman (2003) in an adapted version to make it suitable for young children. In the present study, children first heard an aurally presented sentence containing a verb and then watched movies of naturalistic action sequences matching the presented verb. In order to control for language-general impacts on action perception we used two control conditions next to a familiar label condition; a baseline sentence condition containing no verb and a novel verb condition containing pseudowords. Action perception was assessed using action prediction, We measured infants‘ anticipatory eye movements by means of eye-tracking technology. The measurement of anticipatory eye movements, or more specifically, the fact that an observer fixates the goal of an observed action before the action completed serves as an indicator that an observer has built a representation of the goal of the observed action, and can predict the outcome of the action before it is actually completed (Flanagan & Johansson, 2003). This measure has been shown to be adequate for the study of infants' action prediction (Cannon, Woodward, Gredebäck, von Hofsten, & Turek, 2012; Falck-Ytter et al., 2006; Gredebäck & Kochukhova, 2010; Melzer, Prinz, & Daum, 2012).

For answering the first research question about the point in time, we tested children between the age of 12 months (i.e., the age when they start to produced their first words Kauschke & Hofmeister, 2002) and 24 months (i.e., the age when they are already quite sophisticated word users and learners; Arunachalam & Waxman, 2009; Waxman, Lidz, Braun, & Lavin, 2009). In order to investigate the question after the prerequisites, we manipulated the ages of acquisition of the verbs presented. Using normative data on the acquisition of language, we generated early verbs' actions and late verbs' actions. Early acquired verbs were already produced by the majority of the 24-month-olds whereas late acquired verbs were first produced by the majority of 30-month-old children but were in the perceptive repertoire of the 24 month olds. Additionally, novel control actions were employed. The age of acquisition (AoA) refers to the age at which a word is learnt and has been proposed as a significant contributor to language and memory processes (Barry, Morrison, & Ellis, 1997; Carroll &

White, 1973; Cuetos, Ellis, & Alvarez, 1999; Vitkovitch & Tyrrell, 1995). Specifically, it has been shown in adults that early acquired words are processed faster and easier than late acquired words. This has been called the "AoA effect" (Carroll & White, 1973). AoA effects were also found in children aged between three to seven years (Funnell, Hughes, & Woodcock, 2006).

With this paradigm, we tested the questions proposed above: If linguistic representations do influence non-linguistic representations, then the verb information of the label condition will prime action prediction resulting in a facilitatory effect, indicated by faster anticipation times in the label condition compared to the baseline condition. Furthermore, if the interrelation between linguistic and non-linguistic representations is age-dependent, no AoA effect should be found; the facilitation effect in the label condition should be independent of whether a respective verb is acquired early or late. In contrast, if the interrelation is item-specific, a facilitation effect in the label condition should be found at an earlier age for early acquired words, and at a later age for late-acquired words.

This paradigm was applied in two experiments. In Experiment 1, the AoA of the verbs in the familiar label condition was manipulated and compared to two control conditions. In Experiment 2, we controlled for the saliency of the actions as a possible confounding factor in Experiment 1.

## 7.2 Experiment 1

In Experiment 1, three types of actions were presented, based on the AoA of the corresponding action labels (early action, late action, novel action). Early and late actions were defined by their corresponding linguistic AoA, as taken from normative acquisition data in infancy (Fenson et al., 1993). For novel actions, we presented unfamiliar actions that infants have most likely not observed before. The novel actions served as a control action type. The actions were presented in three conditions that differed according to the label that was provided (familiar label, baseline label, novel label). In the familiar label condition, the label that corresponded to the action was presented. This condition was then compared to two control conditions:  in the baseline label condition, no specific verb label was presented, and in the novel label condition, the label consisted of a pseudo word. All action types were combined with all label conditions in a 3 x 3 within-subject-design.

### 7.2.1 Method

**Participants**

We tested and analyzed data from 72 children in three age groups (12-month-olds:

*N* = 18, 9 girls, *M* = 12.7, *SD* = 0.25, 18-month-olds: *N* = 27, 14 girls, *M* = 18.7, *SD* = 0.25; 24-month-olds: *N* = 27, 14 girls, *M* = 24.6, *SD* = 0.26). Twenty-seven additional children were tested but excluded from the final analysis due to lack of attention during the action perception task (12-month-olds: *n* = 11, 18-month-olds: *n* = 4, 24-month-olds: *n* = 2); or an insufficient number of data points in one or more videos (12-month-olds: *n* = 3, 18-month-olds: *n* = 4, 24-month-olds: *n* = 3). Toddlers were recruited from a database of parents who had previously volunteered to participate in child development studies in a mid-sized German city. The children were all monolingual native German speakers and came from heterogeneous socioeconomic backgrounds. They received a present at the end of the session. The study was approved by the local ethics committee.

**Materials & Design**

In a 3 x 3 within subjects design, three different action types (early action, late action, novel action) were presented in three different label conditions (baseline label, familiar label, novel label).

***Action Types.*** The actions were defined as early and late according to the (early or late) AoA of the action verb. Novel actions comprised novel (unfamiliar) actions that were newly introduced during the experiment and served as a control. The normative AoA data for the early and late actions was taken from the German version of the MacArthur-Bates Communicative Development Inventories (Fenson et al., 1993) FRAKIS (Fragebogen zur frühkindlichen Sprachentwicklung, Szagun, Stumper, & Schramm, 2009). The production of early acquired action verbs starts at 18 months of age (18 months: 15%; 24 months: 60%; 30 months: 95%) and the production of late acquired action verbs starts at 24 months of age (18 months: 0%; 24 months: 15%; 30 months: 65%).

Each action comprised one means object and one goal object. Early actions were “driving” (driving a car into a garage), “building” (building a tower with the last block) and “eating” (having an elephant eat from a spoon). Late actions were “writing” (writing on a sheet of paper with a pencil), “pouring” (pouring into small bowls out of a cup) and “toweling” (toweling a duck with a washcloth). Three novel actions were presented labeled as follows: “novel action A” (Velcro-fastening a ball onto a flat sphere), “novel action B” (threading a stick into a wooden ring) and “novel action C” (hiding a wooden block under a hemisphere). See Figure 1 for an overview of all presented actions.

We counterbalanced the directionality of the actions in order to avoid carry-over effects between the conditions, resulting in three vertical directions (one for each action type: eat, write, novel action A) and six diagonal directions (two for every action type: drive, build, pour, dry, novel action B, novel action C), within these directions the left-right and bottom-up orientations were also counterbalanced. See Table A.1 for an overview of all actions and their corresponding means, goals, directionalities and orientations.

***Label Types.*** The children were verbally primed, either with a neutral description ("I'll show you something", *baseline label condition*), or explicitly with a familiar verb ("I'll show you [familiar verb]", *familiar label condition*) or a novel verb ("I'll show you [novel verb]", *novel label condition*). The words used in the novel label condition were pseudo words that contained a suffix indicating that they were verbs. In the *familiar label condition*, the early actions were labeled "essen" [eat], "fahren" [ride], "bauen" [build]; the late actions were labeled "schreiben" [write], "schütten" [pour], "trocknen" [towel] and the novel action was labeled "schlafen" [sleep]. Because each child saw only one novel action (A, B, or C) in the familiar label condition, only one respective labeling verb was necessary. In the *novel label condition*, the early action was labeled "dupen", the late action was labeled "tammen" and the novel actions were labeled "baffen" [novel action A], "fieben" [novel action B] and "doxen" [novel action C].

***Videos.*** In all videos, one means object was grasped and transported to the goal object. They consisted of four phases: start-up phase, means phase, goal phase and effect phase. All means and goal objects in the different videos were of similar size (original size in cm: 4 x 4 cm, visual angle of the video presentation at the infant's viewing distance of 60 cm: 4 x 4° visual angle) and were differently colored. In the start-up phase both objects were presented on a table, a human clenched hand was in the middle between these two objects, and the verbal priming was presented. In the means phase (1840 ms) the clenched hand was then lifted up (840 ms), moved towards the mean and simultaneously opened in order to grasp the corresponding object (7.2°/sec). In the goal phase (1000 ms) the hand then moved the mean onto/into the goal object (13.3°/sec). The sequence was completed with an action effect, together with a funny sound (effect phase, 840 ms).

### *Procedure*

After a short familiarization and instruction phase in a play room, the experimental session began in a test room. During the prediction task, the children's eye movements were measured using a Tobii 1750 near infrared eye-tracker with an infant add-on (Tobii Technology AB, Stockholm, Sweden; precision: 1°, accuracy: 0.5°, sampling rate: 50 Hz).

The stimulus material was presented using the software Clearview 2.7.1. A 9-point infant calibration was used. During calibration, a blue and white sphere expanded and contracted (extended diameter = 3.3°) in synchrony with a sound. After the calibration, a total of nine videos were presented in the prediction task, one video for every possible combination of action type (early action, late action, novel action) and label condition (baseline label, familiar label, novel label). The combinations were latin-square balanced and each child was randomly assigned to one of these orders. Each combination was presented five successive times with a salient attention-grabber being presented before the first and the fourth presentation.

A play phase was introduced after each video, in order to allow for a break between the video sequences, and to make the task more diverse for the children. In the play phase the toddlers were given the objects (means, goal) on a plate in the same arrangement as seen in the prediction task and had the opportunity to play with them. The objects were presented on a table which was located between the eye tracker and the infant's chair. This play phase finished when children successfully imitated the action, stopped acting on the objects, or when they did not act on any of the objects for a maximum of 45 sec.

***Data analysis***

To analyze the data, recorded gaze points (x- and y-coordinates) from the right and left eye were averaged. If data from one eye only were available, this was used instead of the averaged data point. The goal area of interest (AOI) was the area where the means object was located within the respective action. For all videos the same dimensions of the AOI were used, (width = 4.46°; height = 4.72°). The means object was chosen as the AOI because the object to be selected was ambiguous in the means phase, whereas it was unambiguous in the goal phase. Thus, no differences were expected in the goal phase. We analyzed eye movements to the AOI during the means phase, that is 1840ms after the onset of the video to ensure that no initial fixation at the onset of the video was measured. This furthermore ensured that only anticipations after the end of the verbal information were included. The difference between the point in time when the hand entered the AOI of the respective action, and the point in time when the observing child first looked at the same AOI during this means phase was calculated. This difference (anticipation time) provides a measure of whether the toddlers anticipated the action goal (gaze arrived at AOI prior to hand), or if they tracked the observed events in a reactive manner (gaze arrived at AOI after hand). Only the first trial of each video was analyzed because our goal was to investigate the influence of the verb semantics on action prediction and not learning from previously seen sequences of the same action. Anticipation times above 1000 ms mean that infants made predictive eye gaze prior to any directive information provided by the hand.

In general, the anticipation of the action goal was possible without any processing of the additional verbal information. Accordingly, the raw anticipation times are to some extent uninformative for our present research questions. To this end, in order to assess the influence of the verb semantics on the prediction of the actions, the anticipation times of the familiar label and the novel label conditions were compared to the anticipation times of the baseline condition. For each action type, and each age group, the baseline difference (BLD) from the two experimental label conditions was calculated. The BLD measures were calculated as follows: For each age group (12, 18, 24 months) and each action type (early action, late action, novel action) separately the mean anticipation time from all children in the baseline label condition was calculated. This resulted in three baseline measures fore each age group and in a total of nine baseline measures used. The mean of all toddlers was used in order to account for differences in the three sub actions of each action type that were shown in the baseline label condition. This baseline mean was then subtracted from the individual anticipation times in the *familiar label condition* (BLD familiar label) and in the *novel label condition* (BLD novel label). Negative values in these *baseline differences* reflect slower anticipation (interference effect) and positive values reflect faster anticipation (facilitation effect) as compared to the anticipations of the *baseline label condition*. If the verb semantics have a significant influence on action perception, this would result in a change to the anticipation time, reflected by the BLD. Likewise, possible age effects or differences between the action types in the action prediction proficiency do not need to be considered. For all measures used, the higher the value is, the more pronounce the facilitatory effect of the verbal information was.

### 7.2.2 Results

A preliminary analysis revealed no effects of gender or order of action types on the BLD. We therefore collapsed data across these factors. As a prior analysis we were interested whether the age groups tested were able to anticipate the means objects before they were grasped. We ran separate t-tests for the baseline label conditions of all three action types against 0 (the hand grasps the object) and found that all age groups were able to anticipate the means object in all action types, all $p$s < .001. Anticipations were made almost exclusively during the phase were the clenched hand was lifted up before any directive information was given. The only exceptions were the novel actions in the 18-month-olds (see Table A.2).

The current research addresses two key research questions: 1) At what point in time does linguistic information change the perception of actions? And 2) What are the prerequisites for the potential interrelation between linguistic and non-linguistic representations? To answer our first research question, we need to identify age at which a difference between the baseline label condition and the familiar label condition occurs. Accordingly, the BLD measures of the three age groups were tested against 0 using one-sample $t$-tests. To answer the second question, the influence of verb semantics needs to be compared in relation to the different action types. Accordingly, the BLD measures of the different action types were compared to each other using an analysis of variance (ANOVA) and post-hoc comparisons. $P$-values are reported two-tailed throughout.

**Action Prediction.** The BLD familiar label and the BLD novel label measures were analyzed using separate $t$-tests to assess whether language processing led to a significant difference from 0 (the baseline label condition). See Table 1 for an overview of the mean BLD measures in each age group, action type and label condition and the corresponding $t$-tests.

In the 12-month-olds no significant effects were found in any of the measures (all $p$s > .07). In the 18-month-olds a significant effect was found for the BLD familiar label measure of the novel action $t(26) = 2.852$, $p = .008$, but in no other BLD measure (all $p$s > .38). We corrected for multiple testing and the Fisher's Omnibus test did not reach significance, indicating that the result in the novel action was possibly a simple byproduct of multiple testing, $df = 12$, $\chi^2 = 14.13$, $p = .12$. In the 24-month-olds a significant difference in the BLD familiar label measure of the early action was found ($t(26) = 3.68$, $p = .001$), but in no other BLD measure. We again corrected for multiple testing and the Fisher's Omnibus test reached significance, indicating that the significant result in the early action was not a simple byproduct of multiple testing, $df = 12$, $\chi^2 = 24.03$, $p = .02$.

These results show that only familiar labels of the early actions lead to a significant difference from the baseline label condition in 24-month-olds. These toddlers predicted the action faster. See Figure 2 for the results in the early actions. No such effect was found for younger toddlers or in the other action types.

Additionally, we were interested in a developmental perspective on the influence of age on language in the early actions. This analysis was restricted to the early actions as no differences were found in the late or novel actions. Finding an age effect on a BLD measure would lead to the interpretation that the integration of language to action takes place gradually. Using an ANOVA with age as between-subjects factor and BLD familiar label measure as the dependent variable, revealed an age effect, $F(2, 69) = 6.6$, $p = .002$. Post-hoc tests showed a developmental change in the directionality of the influence: 12-month-olds were negatively influenced by language ($M = -373$, $SE = 198$) and the 24-month-olds were positively influenced ($M = 453$, $SE = 123$), $t(43) = -3.38$, $p = .001$. No such effect was found for the late actions, $F(2, 69) = 0.97$, $p = .39$. This gradual integration of language was furthermore attested to by a significant correlation between age and the BLD familiar label measure, Pearson Correlation $r(72) = .401$, $p < .001$.

The developmental data show that the influence of language increases over time, suggesting a gradual integration of language into action and the link already beginning to be present at 12 months of age.

**Language Skills.** Next, we investigated the item-specificity of the link between action and language. The findings above showed that early acquired but not late acquired verbs facilitated action prediction. Here, we analyzed at what age children differentiate between the action types, that is, which age group differed in their BLDs between early and late or novel actions. Three separate ANOVAs for each age group were conducted with Action Type (BLD early action, BLD late action, BLD novel action) as within-subjects factor. Only the 24-month-olds revealed a main effect for Action Type, $F(1, 26) = 8.37$, $p = .002$, with post-hoc tests showing that familiar verbs in early actions ($M = 344.62$, $SD = 421.23$) resulted in faster anticipation times than in late actions ($M = 57.4$, $SD = 491.24$, $F(1, 26) = 6.11$, $p = .02$) and than in novel actions ($M = 112.92$, $SD = 486.05$), $F(1, 26) = 15.26$, $p = .001$. None of the younger age groups showed a main effect for action type (all $p$s > .13). The same analyses were also conducted with the novel verbs but no age group showed a main effect for action type in this label condition (all $p$s > .42). This null result provides evidence that the item-specificity found was not mediated by the verbs per se but the semantic information of the familiar verbs involved.

A further analysis was carried out to control for general linguistic skills. We ran correlational analysis between the BLD familiar action and the productive verbal skills as assessed by the word-list of FRAKIS (Szagun) in each age group. None of the three correlations was significant, 12-month-olds: $r(18) = -0.143$, $p = .571$; 18-month-olds: $r(27) = -0.044$, $p = .828$; 24-month-olds: $r(27) = -0.101$, $p = .632$. To double-check this finding, we conducted median-split t-test and tested whether high-producers predicted differently than low-producers and we again found no significant results, 12-month-olds: $t(16) = -0.325$, $p = .75$; 18-month-olds: $t(25) = -0.63$, $p = .534$; 24-month-olds: $t(16) = 0.123$, $p = .903$.

The 24-month-old children, but not the younger children, made a differentiation between early and late acquired verbs. This confirms the results in the previous section, showing that only early acquired verbs lead to faster anticipation times, compared to the baseline condition. This finding was not mediated by general production skills but by item-specific verb production skills.

### 7.2.3 Discussion

The results of Experiment 1 suggest that language influences action perception at an early age. We found that an orally presented verb facilitated the prediction of the respective (early) action. Twenty-four-month-old toddlers showed a faster anticipation of early actions when primed with the corresponding verb in the familiar label condition compared to the baseline label condition. A similar facilitation of action prediction caused by verb semantics as has been found in adults (Springer & Prinz, 2010), is present already at the age of 24 months. In contrast to the facilitatory effect of language on action occurring at 24 months, the language seems interfere with action earlier in life at the age of 12 months. This gradual integration of language reflects previous findings reported from longitudinal rather than cross-secitonal studies (Bates et al., 1979; Capirci et al., 2005; Carpenter et al., 1998; Lifter & Bloom, 1989; Thelen, 1979). In combination, these results might be interpreted in the following way: Already at the onset of language production, linguistic and non-linguistic representations are communicating with each other. However, at the onset of this communication the processing of both information results in an increase in processing time. One year later, the linguistic information can then facilitate the perception of a corresponding action.

At the age of 24 months, another interesting result was found. At this age, the children differentiated in their anticipation times between early and late actions. Early actions were processed faster. While the prediction of early actions was facilitated, no difference from baseline was found in the late actions. This suggests that the influence of language on action develops item-specifically: Verbs that are, according to the FRAKIS (Szagun et al., 2009), already produced by a majority of 24-month-olds result in an enhanced action prediction, while verbs that are produced by only a minority of children at this age did not result in any difference of the anticipation times from baseline. These results confirm and complement previous findings on the AoA at later ages (Barry et al., 1997; Carroll & White, 1973; Cuetos et al., 1999; Morrison, Ellis, & Quinlan, 1992; Vitkovitch & Tyrrell, 1995).

The results of Experiment 1 are rather clear-cut. However, there is one confounding factor that needs to be controlled for. It remains an open question, whether the different processing of early and late acquired actions were really due to the linguistic age of acquisition (i.e., the age at which the respective action verb is acquired). It might be equally as likely that the saliency of the action accounts for the null results in the late actions. If the children perceived the late actions in another way than the early actions, then no interference or facilitation effects of language might be expected (Boulenger, Décoppet, Roy, Paulignan, & Nazir, 2007; James & Swain, 2011; Maouene, Hidaka, & Smith, 2008). We tested this alternative explanation in Experiment 2, where we additionally controlled for the saliency of the actions used.

## 7.3 Experiment 2

In Experiment 2 we assessed whether the difference between early and late labels would still exist if the actions were controlled for their saliency. If the non-facilitating effect of language on the perception of late actions in Experiment 1 was in fact due to the different saliency of the late actions, the difference should not appear if the same actions were used with early and late verbs. We thus simplified the design of Experiment 1 and presented only four of the actions. Two of those four actions were labeled with a corresponding early familiar label of Experiment 1 (i.e., “build”) and the other two with a related late familiar label (i.e., “stack”). We tested 18- and 24-month-olds only because the 12-month-olds did not show any facilitation effect in any of the action types used in Experiment 1. If the item-specific linkage found in Experiment 1 was not due to the saliency of the action itself but was instead induced by the semantics of the early and late labels, we would expect to find a similar difference between early and late labels in Experiment 2 as well.

### 7.3.1 Methods

**Participants**

We tested and analyzed data from children in two age groups (18-month-olds: $N = 24$, 12 girls, $M = 18.7$, $SD = 0.26$; 24-month-olds: $N = 24$, 12 girls, $M = 24.7$, $SD = 0.25$). Five additional children were tested but excluded from the analysis due to lack of attention during the action perception task (18-month-olds: $n = 1$); or an insufficient number of data points in one or more videos (18-month-olds: $n = 3$, 24-month-olds: $n = 1$).

**Design, Materials, and Procedure.**

Four videos were presented in the prediction task: two experimental videos for every label condition (early label condition, late label condition). The videos of the early and late label conditions were presented in blocks. The order of the condition blocks and the videos within the blocks were counterbalanced between children. Children were randomly assigned to one of the resulting eight orders. The videos of the early actions (see Figure 1, panel a) and the "writing" action of Experiment 1 were used as experimental videos. Two of the videos were labeled with an early acquired verb ("build", "eat", "drive", "paint") and the other two with a late acquired verb ("stack", "feed", "park", "write"). Both, the early and the late labels of a respective action denoted the same action, but the late labels were acquired at a later point in development. The same AoAs for the early and late labels and the same procedure as in Experiment 1 were used.

**Data Analysis**

The anticipation times were calculated in the same way as in Experiment 1. The anticipation times for the two early-labeled actions were averaged, as were the anticipation times for the two late-labeled actions.

Additionally, in order to compare the results obtained in Experiment 2 to those of Experiment 1, we again calculated the BLD measures for the early and the late label conditions. We averaged the anticipation times of the baseline label condition of Experiment 1 for those four actions involved, for each age group (18, 24) separately. The anticipation times in the early and the late label conditions were then subtracted by this baseline mean. Doing so allows investigating whether the facilitation found in the familiar label condition of the early actions of Experiment 1 could also be found in Experiment 2.

### 7.3.2 Results

A preliminary analysis revealed no effects of gender or order of action types. We therefore collapsed data across these factors.

We tested whether toddlers processed the label conditions differently using a 2 x 2 (Label Condition [early label, late label], Age [18, 24]) ANOVA with label condition as the within-subjects-factor and age as the between-subjects-factor. This revealed a main effect for label condition, $F(1, 46) = 5.595$, $p = .02$, showing that actions in the early label condition were anticipated faster ($M = 1349.37$ ms, $SD = 462.86$ ms) than actions in the late label condition ($M = 1131.04$ ms, $SD = 440.81$ ms).

Based on the differential findings in the two age groups in Experiment 1, we ran separate planned comparisons for the two age groups. This analysis revealed that the 24-month-olds showed a differentiation between the label conditions, $t(23) = 4.26$, $p = .05$, but not the 18-

month-olds, $t(23) = 1.7$, $p = .20$. The 24-month-olds in Experiment 2 processed early labels faster than late labels.

We then ran baseline comparisons using t-tests in order to see whether the anticipation times were different from the baseline label mean of Experiment 1 for the BLD early label and the BLD late label. The early labels were found to be faster processed than the baseline mean, $t(47) = 2.55$, $p = .014$, while late labels did not differ from baseline, $t(47) = -0.74$, $p = .461$.

We again ran separate planned comparisons for the two age groups in the BLD early label and found that only the 24-month-olds were faster in the early label condition, $t(23) = 2.61$, $p = .01$, compared to the baseline mean of Experiment 1, but no difference was found for the 18-month-olds, $t(23) = 1.14$, $p = .265$). See Table 2 for an overview of the means and standard deviations for Experiment 2.

### 7.3.3 Discussion

In Experiment 2, where we controlled for a saliency of the action (Boulenger et al., 2007; James & Swain, 2011; Maouene et al., 2008), we confirmed the difference between early and late acquired labels that was found in Experiment 1. Actions whose corresponding verb is acquired early were processed faster than late acquired ones and faster than the baseline of Experiment 1. These results suggest that the facilitation effect found for early-acquired verbs in Experiment 1 was not induced by a different perception of the late actions but due to the linguistic AoA. The findings are again in line with previous findings for AoA effects (Barry et al., 1997; Carroll & White, 1973; Cuetos et al., 1999; Morrison et al., 1992; Vitkovitch & Tyrrell, 1995) and, additionally, support the findings of Experiment 1, indicating an item-specific influence of language on action prediction.

## 7.4 General Discussion

In two experiments, we investigated the influence of language on action prediction in children between 12 and 24 months of age. The main research questions were 1) At which point in time does linguistic information change the perception of actions? 2) And which prerequisites are necessary for this interrelation between linguistic and non-linguistic representations? To answer these two questions, a modified version of the paradigms introduced by Springer & Prinz (2010) and Nation, Marshall & Altman (2003) was used, and action prediction was measured via anticipatory eye movements. The linguistic AoA of the labels of the actions presented was manipulated. In Experiment 1, early and late actions (defined according to the AoA of the action labels, Szagun et al, 2009), as well as novel actions, were labeled with a familiar or novel label and compared to a baseline condition with no specific label involved. In Experiment 2 only the early actions of Experiment 1 were used and labeled either with the corresponding early label or a fitting late label.

In light of the results, it seems appropriate to conclude that language influences action prediction by the age of 12 months. However, this was only the case for the early actions and, in contrast to adults (Springer & Prinz, 2010), its impact was interfering. Given the fact that, 12 months later, at 24 months of age, an adult-like facilitating impact occurs in the early actions, the question arises about the developmental trajectory of this influence. One possibility is that linguistic and non-linguistic representations start to communicate with each other before being usable for each other. At this first stage, the processing of both linguistic and non-linguistic information results in an interference of the two information types. One reason for this might be the limited semantic information available at this age. Recent research has shown interference effects in a mental simulation task with older children, in cases where the linguistic and the action information did not coincide (Engelen, Bouwmeester, de Bruin, & Zwaan, 2011). In the present study, we might have created a comparable situation early in infancy because the stimulus material used can be viewed as a dual task where language and action are encoded. After this initial stage of communication, children enter the stage of an adult-like facilitation of language on action at the age of 24 months old. It is important to note that we controlled for a the mere existence of language as an interfering factor. All action types were not only labeled by the corresponding label but also by a novel label. The aim of this procedure was to preclude that a verbal label per se could lead to different processing of the actions. The results of this novel label condition did not demonstrate similar interfering or facilitating impacts on action prediction. Accordingly, the interference effect in the 12-month-olds is based on the processing of an additionally given verbal cue but on the specific and corresponding action verb. The previous findings regarding the influence of a novel label on visual processing are, however, a matter of controversy. While some studies found no interfering effects in toddlers aged over one year (Robinson & Sloutsky, 2007; Sloutsky & Robinson, 2008), others found that interference could still occur (Mather, Schafer, & Houston-Price, 2011). More research is needed to disentangle the differences found. Taken together, our results show that familiar language information can be used to predict forthcoming actions and not only referents (Mani & Huettig, 2012; Nation et al., 2003). We can further attest that this ability develops gradually.

Regarding the second research question, the requirements for an interrelation between linguistic and non-linguistic representations can be inferred by the results of the different

AoA. The AoA has been proposed as a significant contributor to language and memory processes in adults (Barry et al., 1997; Carroll & White, 1973; Cuetos et al., 1999; Morrison et al., 1992; Vitkovitch & Tyrrell, 1995), and was also found in children (Funnell et al., 2006). The results from the present study demonstrate an AoA effect in a further domain, namely action perception, in children. They additionally suggest an item-specific development of the influence of language on action perception: Only the early labels that were actively produced by the majority of 24-month-olds had a facilitating effect on action prediction. At the ages investigated, no facilitatory effect was found for late actions, even when the actions were controlled for their saliency in Experiment 2 (Boulenger et al., 2007; James & Swain, 2011; Maouene et al., 2008).

The present results speak for an AoA effect already being present early in life that is not restricted to naming speed in word and picture tasks, but which affects the prediction of an observed action. An analogous study in adults found that the AoA of verbs is related to the corresponding age of the onset of the specific action production skill. Maouene, Hidaka and Smith (2008) asked adults to name the body part that first came into their mind when reading each of 101 verbs that were normatively acquired prior to the age of 3. The analysis revealed systematic patterns of associations that are related to the normative age of acquisition and a progression from verbs associated with actions by the mouth (acquired around 21 and 22 months of age), to verbs associated with actions by hand and arm (acquired around 22 to 27 months of age), and finally those verbs that were not strongly associated with any one body part (acquired after 28 months of age). On the basis of an adult rating, this study gives further evidence for the item-specific impact of language on action domains.

Concerning the findings, it is interesting to speculate on the interrelations between linguistic and non-linguistic representations from a developmental perspective. The results from this study can be taken an indication of a common representation of language and action on a behavioral level. Similar to adults (Buccino et al., 2005; Glenberg & Kaschak, 2002; Rueschmeyer, Lindemann, Rooij, Dam, & Bekkering, 2010; Springer & Prinz, 2010), this common representation was also found in preschool and school-aged children (Engelen et al., 2011; James & Maouene, 2009). Pickering & Garodd (2007) argued that productive linguistic skills support the prediction and anticipation in other’s actions. Results from this study support this claim. Only those verbs that were productively used by the children lead to a facilitation in action prediction, verbs on the perceptive level lead to an interference. The current results might support a shared representation of language and action as the prior knowledge of the verb lead to a faster anticipation in 24-month-old children. However, as data in these experiments were only on a behavioral level, further research is needed to support or disprove this speculation.

To conclude, the results of the two experiments suggest that language is influential on action perception from early on while the successful facilitatory influence depends on the productive repertoire of the language in question.

## References


Arunachalam, S., & Waxman, S. (2009). Meaning from syntax: Evidence from 2-year-olds. *Cognition*, *114*, 442–446.

Balaban, M. T., & Waxman, S. R. (1997). Do Words Facilitate Object Categorization in 9-Month-Old Infants? *Journal of Experimental Child Psychology*, *64*(1), 3–26. doi:10.1006/jecp.1996.2332

Baldwin, D. A., & Markman, E. M. (1989). Establishing word-object relations: A first step. *Child Development*, *60*, 381–398.

Barry, C., Morrison, C. M., & Ellis, A. W. (1997). Naming the snodgrass and vanderwart pictures: effects of age of acquisition, frequency, and name agreement. *The Quarterly Journal of Experimental Psychology Section*, *50*, 560–585.

Bates, E., Benigni, L., Bretherton, I., Camaioni, L., & Volterra, V. (1979). *The emergence of symbols: Cognition and communication in infancy.* New York: Academic Press.

Biro, S., & Leslie, A. M. (2007). Infants' perception of goal-directed actions: development through cue-based bootstrapping. *Developmental Science*, *10*(3), 379–398. doi:10.1111/j.1467-7687.2006.00544.x

Boulenger, V., Décoppet, N., Roy, A. C., Paulignan, Y., & Nazir, T. A. (2007). Differential effects of age-of-acquisition for concrete nouns and action verbs: Evidence for partly distinct representations? *Cognition*, *103*, 131–146. doi:10.1016/j.cognition.2006.03.001

Bruner, J. S. (1964). The course of cognitive growth. *American Psychologist*, *19*(1), 1–15. doi:10.1037/h0044160

Buccino, G., Riggio, L., Melli, G., Binkofski, F., Gallese, V., & Rizzolatti, G. (2005). Listening to action-related sentences modulates the activity of the motor system: A combined TMS and behavioral study. *Cognitive Brain Research*, *24*, 355–363.

Cannon, E. N., Woodward, A. L., Gredebäck, G., von Hofsten, C., & Turek, C. (2012). Action production influences 12-month-old infants' attention to others' actions. *Developmental Science*, *15*, 35–42. doi:10.1111/j.1467-7687.2011.01095.x

Capirci, O., Contaldo, A., Caselli, M. C., & Volterra, V. (2005). From action to language through gesture: A longitudinal perspective. *Gesture*, *5*(1-2), 155–177. doi:10.1075/gest.5.1.12cap

Carpenter, M., Akhtar, N., & Tomasello, M. (1998). Fourteen- through 18-month-old infants differentially imitate intentional and accidental actions. *Infant Behavior & Development*, *21*, 315–330.

Carroll, J. B., & White, M. N. (1973). Word frequency and age of acquisition as determiners of picture-naming latency. *Quarterly Journal of Experimental Psychology*, *25*, 85–95. doi:10.1080/14640747308400325

Cuetos, F., Ellis, A. W., & Alvarez, B. (1999). Naming times for the snodgrass and vanderwart pictures in spanish. *Behaviour Research Methods*, *31*, 650–658. doi:10.3758/BF03200741

Daum, M. M., Ulber, J., & Gredebäck, G. (in press). The development of pointing comprehension in infancy: Communicative speech supports shifts of covert attention. *Developmental Psychology*.

Engelen, J. A. A., Bouwmeester, S., de Bruin, A. B. H., & Zwaan, R. A. (2011). Perceptual simulation in developing language comprehension. *Journal of Experimental Child Psychology*, *110*, 659–675.

Falck-Ytter, T., Gredebäck, G., & von Hofsten, C. (2006). Infants predict other people's action goals. *Nature Neuroscience*, *9*, 878–879.

Fenson, L., Dale, P. S., Reznick, J. S., Thal, D., Bates, E., Hartung, J. P., Pethick, S., et al. (1993). *The MacArthur Communicative Development Inventories: User's Guide and Technical Manual*. Baltimore: Paul H. Brokes Publishing Co.

Flanagan, J. R., & Johansson, R. S. (2003). Action plans used in action observation. *Nature*, *424*, 769–771.

Fulkerson, A. L., & Waxman, S. R. (2007). Words (but not Tones) facilitate object categorization: Evidence from 6- and 12-month-olds. *Cognition*, *105*(1), 218–228. doi:10.1016/j.cognition.2006.09.005

Funnell, E., Hughes, D., & Woodcock, J. (2006). Age of acquisition for naming and knowing: A new hypothesis. *The Quarterly Journal of Experimental Psychology*, *59*, 268–295. doi:10.1080/02724980443000674

Gergely, G., Nádasdy, Z., Csibra, G., & Bíró, S. (1995). Taking the intentional stance at 12 months of age. *Cognition*, *56*(2), 165–193. doi:10.1016/0010-0277(95)00661-H

Glenberg, A. M., & Kaschak, M. P. (2002). Grounding language in action. *Psychonomic Bullentin & Review*, *9*, 558–565.

Graham, S. A., & Kilbreath, C. S. (2007). It's a sign of the kind: Gestures and words guide infants' inductive inferences. *Developmental Psychology*, *43*(5), 1111–1123. doi:10.1037/0012-1649.43.5.1111

Gredebäck, G., & Kochukhova, O. (2010). Goal anticipation during action observation is influenced by synonymous action capabilities, a puzzling developmental study. *Experimental Brain Research*, *202*(2), 493–497. doi:10.1007/s00221-009-2138-1

James, K. H., & Maouene, J. (2009). Auditory verb perception recruits motor system in the developing brain: an fMRI investigation. *Developmental Science*, F26–F34.

James, K. H., & Swain, S. N. (2011). Only self-generated actions create sensori-motor systems in the developing brain. *Developmental Science*, *14*, 673–678.

Kauschke, C., & Hofmeister, C. (2002). Early lexical development in German: a study on vocabulary growth and vocabulary composition during the second and third year of life. *Child Language*, *29*, 735–757.

Kosslyn, S. M. (1978). The representational-development hypothesis. In P. A. Ornstein (Ed.), *Memory development in children*. Hillsdale, NJ: Erlbaum.

Lifter, K., & Bloom, L. (1989). Object knowledge and the emergence of language. *Infant Behavior and Development*, *12*(4), 395–423. doi:10.1016/0163-6383(89)90023-4

Mani, N., & Huettig, F. (2012). Prediction during language processing is a piece of cake—But only for skilled producers. *Journal of Experimental Psychology: Human Perception and Performance*, *38*(4), 843–847. doi:10.1037/a0029284

Maouene, J., Hidaka, S., & Smith, L. (2008). Body Parts and Early-Learned Verbs. *Cognitive Science*, *32*, 1200–1216. doi:Doi 10.1080/03640210802019997

Mather, E., Schafer, G., & Houston-Price, C. (2011). The impact of novel labels on visual processing during infancy. *British Journal of Developmental Psychology*, *29*, 783–805. doi:10.1348/2044-835X.002008

Melzer, A., Prinz, W., & Daum, M. M. (2012). Production and perception of contralateral reaching: A close link by 12 months of age. *Infant behavior & development*, *35*(3), 570–579. doi:10.1016/j.infbeh.2012.05.003

Morrison, C. M., Ellis, A. W., & Quinlan, T. (1992). Age of acquisition, not word frequency, affects object naming, not object recognition. *Memory & Cognition*, *20*, 705–714. doi:10.3758/BF03202720

Nation, K., Marshall, C. M., & Altmann, G. T. . (2003). Investigating individual differences in children's real-time sentence comprehension using language-mediated eye movements. *Journal of Experimental Child Psychology*, *86*(4), 314–329. doi:10.1016/j.jecp.2003.09.001

Nelson, K. (1973). Structure and Strategy in Learning to Talk. *Monographs of the Society for Research in Child Development*, *149*(1-2), 1–138.

Piaget, J., & Inhelder, B. (1966). *La psychologie de l'enfant*. Paris: Presses Univ. de France.

Pickering, M. J., & Garrod, S. (2007). Do people use language production to make predictions during comprehension? *Trends in Cognitive Sciences*, *11*(3), 105–110. doi:10.1016/j.tics.2006.12.002

Plunkett, K., Hu, J.-F., & Cohen, L. B. (2008). Labels can override perceptual categories in early infancy. *Cognition*, *106*(2), 665–681. doi:10.1016/j.cognition.2007.04.003

Robinson, C. W., & Sloutsky, V. M. (2007). Visual processing speed: effects of auditory input on visual processing. *Developmental Science*, *10*, 734–740. doi:10.1111/j.1467-7687.2007.00627.x

Rodgon, M. M., Jankowski, W., & Alenskas, L. (1977). A multi-functional approach to single-word usage. *Journal of Child Language*, *4*(01), 23–43. doi:10.1017/S0305000900000465

Rueschmeyer, S., Lindemann, S., Rooij, D., Dam, W., & Bekkering, H. (2010). Effects of intentional motor actions on embodied language processing. *Experimental Psychology*, *57*, 260–266.

Sloutsky, V. M., & Robinson, C. W. (2008). The role of words and sounds in infants' visual processing: From overshadowing to attentional tuning. *Cognitive Science*, *32*, 342–365. doi:10.1080/03640210701863495

Springer, A., & Prinz, W. (2010). Action semantics modulate action prediction. *The Quarterly Journal of Experimental Psychology*, *63*, 2141–2158.

Szagun, G., Stumper, B., & Schramm, A. S. (2009). Fragebogen zur frühkindlichen Sprachentwicklung (FRAKIS) und FRAKIS-K (Kurzform). *Frankfurt: Pearson Assessment*.

Thelen, E. (1979). Rhythmical Stereotypies in Normal Human Infants. *Animal Behaviour*, *27*(AUG), 699–715. doi:10.1016/0003-3472(79)90006-X

Topál, J., Gergely, G., Miklósi, Á., Erdöhegyi, Á., & Csibra, G. (2008). Infants' perseverative search errors are induced by pragmatic misinterpretation. *Science*, *321*, 1831–1834.

Vitkovitch, M., & Tyrrell, L. (1995). Sources of disagreement in object naming. *The Quarterly Journal of Experimental Psychology Section*, *48*, 822–848. doi:10.1080/14640749508401419

Waxman, S. R., Lidz, J. L., Braun, I. E., & Lavin, T. (2009). Twenty four-month-old infants' interpretations of novel verbs and nouns in dynamic scenes. *Cognitive Psychology*, *59*, 67–95.

Werner, H. (1926). *Einführung in die Entwicklungspsychologie*. Leipzig: Barth.

Woodward, A. L. (1998). Infants selectively encode the goal object of an actor's reach. *Cognition*, *69*, 1–34.

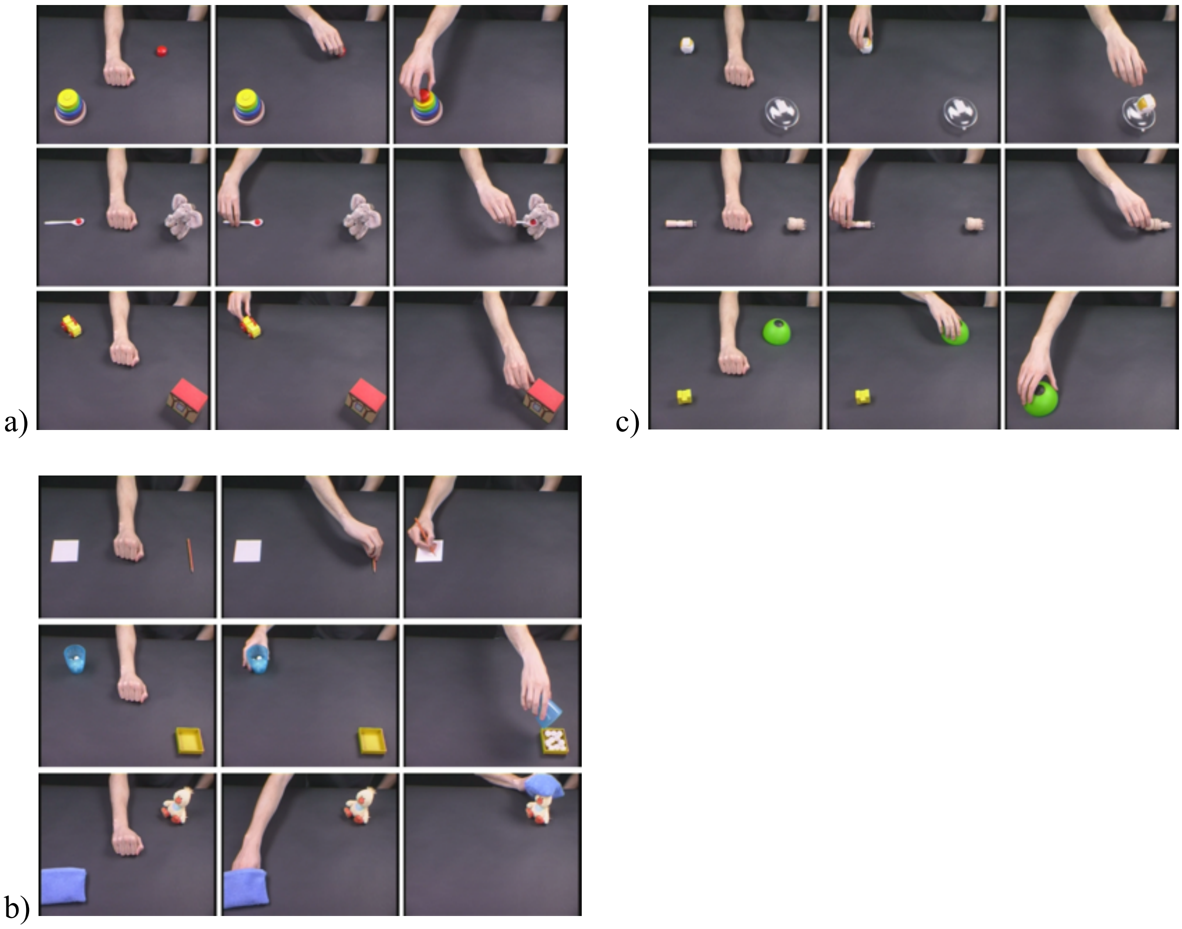


*Figure 1*. Key frames of the actions from left to right: a) early actions (build, eat, drive), b) late actions (write, pour, towel), and c) novel actions used in Experiment 1.

| | BLD familiar | | | | BLD novel | | | |
|---|---|---|---|---|---|---|---|---|
| **Early actions** | ***M*** | ***SD*** | ***t*** | ***p*** | ***M*** | ***SD*** | ***t*** | ***p*** |
| **12 months** | **-372** | **841** | **-1.9** | **.08** | **-225** | **928** | **-1.0** | **.32** |
| **18 months** | **78** | **788** | **0.4** | **.71** | **128** | **757** | **0.9** | **.39** |
| **24 months** | **452** | **639** | **3.7** | **.001** | **236** | **756** | **1.6** | **.12** |
| **Late actions** | ***M*** | ***SD*** | ***t*** | ***p*** | ***M*** | ***SD*** | ***t*** | ***p*** |
| **12 months** | **-223** | **767** | **-1.2** | **.23** | **-115** | **795** | **-0.6** | **.55** |
| **18 months** | **20** | **686** | **0.2** | **.88** | **-68** | **744** | **-0.5** | **.64** |
| **24 months** | **-18** | **671** | **-0.2** | **.89** | **132** | **687** | **1.0** | **.32** |
| **Novel actions** | ***M*** | ***SD*** | ***t*** | ***p*** | ***M*** | ***SD*** | ***t*** | ***p*** |
| **12 months** | **-103** | **828** | **-0.5** | **.61** | **-358** | **792** | **-1.9** | **.07** |
| **18 months** | **386** | **703** | **2.8** | **.008** | **73** | **880** | **0.4** | **.67** |
| **24 months** | **-181** | **-765** | **-1.2** | **.23** | **-44** | **672** | **-0.3** | **.74** |

*Note. M* = Mean; *SD* = Standard Deviation

*Table 1.* Means and standard deviations (in ms), and statistic *t*- and *p*-values of the comparison against baseline of the BLD measures, in the three age groups, for Experiment 1.

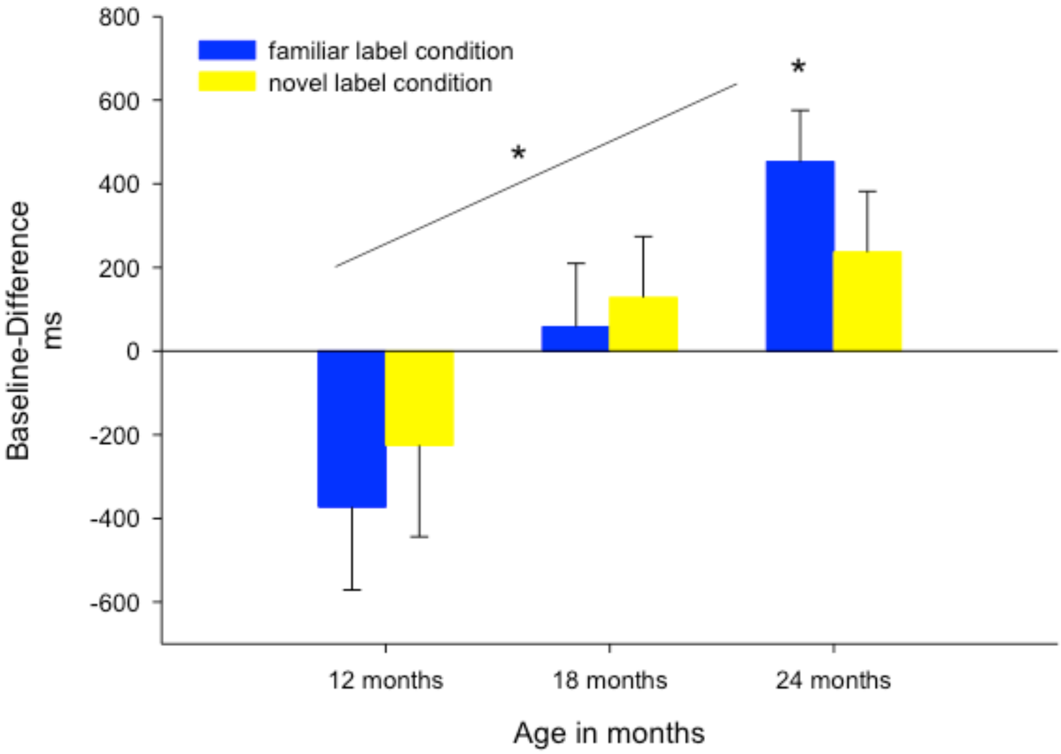


*Figure 2.* Means and standard errors of the BLD measures (in ms), in the three age groups, for the early actions of Experiment 1.

| | *Early Label* | | *Late Label* | | *BLD early* | | *BLD late* | |
|---|---|---|---|---|---|---|---|---|
| | ***M*** | ***SD*** | ***M*** | ***SD*** | ***M*** | ***SD*** | ***M*** | ***SD*** |
| **18 months** | 1307 | 509 | 1132 | 472 | 118 | 509 | -56 | 472 |
| **24 months** | 1390 | 417 | 1129 | 417 | 222 | 418 | -38 | 418 |

*Note. M* = Mean; *SD* = Standard Deviation

*Table 2.* Means and standard deviations (in ms) in the two age groups, for Experiment 2.

## Appendix

*Table A.1*

Actions used with their corresponding means, goals, directionalities and orientations.

| Action | Mean | Goal | Directionality | Orientation |
|---|---|---|---|---|
| **Riding** | car | garage | diagonal | left-right |
| **Building** | block | tower | diagonal | right-left |
| **Eating** | spoon | elephant | vertical | left-right |
| **Writing** | pencil | sheet of paper | vertical | right-left |
| **Pouring** | cup | box | diagonal | left-right |
| **Toweling** | wash-cloth | duck | diagonal | right-left |
| **Novel Action A** | ball | flat sphere | diagonal | left-right |
| **Novel Action B** | stick | hollowed stick | vertical | left-right |
| **Novel Action C** | block | hemisphere | diagonal | right-left |

*Table A.2*

Raw anticipation times (in ms) before substraction from baseline in the three age groups, for Experiment 1.

| | **Baseline Label** | | **Familiar Label** | | **Novel Label** | |
|---|---|---|---|---|---|---|
| **Early actions** | ***M*** | ***SD*** | ***M*** | ***SD*** | ***M*** | ***SD*** |
| **12 months** | 1254 | 870 | 881 | 840 | 1028 | 928 |
| **18 months** | 1034 | 724 | 1091 | 788 | 1162 | 757 |
| **24 months** | 1005 | 782 | 1457 | 639 | 1241 | 756 |
| **Late actions** | ***M*** | ***SD*** | ***M*** | ***SD*** | ***M*** | ***SD*** |
| **12 months** | 1008 | 888 | 784 | 767 | 892 | 795 |
| **18 months** | 1168 | 682 | 1188 | 686 | 1099 | 745 |
| **24 months** | 1130 | 732 | 1112 | 672 | 1263 | 688 |
| **Novel actions** | ***M*** | ***SD*** | ***M*** | ***SD*** | ***M*** | ***SD*** |
| **12 months** | 1313 | 648 | 1210 | 829 | 954 | 793 |
| **18 months** | 899 | 806 | 1285 | 704 | 973 | 881 |
| **24 months** | 1267 | 727 | 1085 | 765 | 1223 | 672 |

*Note. M* = Mean; *SD* = Standard Deviation

# 8 Enactment is beneficial for verb learning in toddlers

Abstract

Embodied theories of language consider language to be an integrative part of the motor representations of actions (Barsalou, 2008). Recent findings further suggest that learning a novel word in second language acquisition is enriched by enactment (Macedonia & Knösche, 2011). We investigated whether action production may also help acquiring the first language. In a simple word-learning study 24-, 30- and 36-month-old children learned the labels of object and motion actions in one of two conditions: in the passive condition children just observed the experimenter executing the action and in the active condition children executed the action themselves. Results showed that 36-month-olds are able to learn object and motion actions in both conditions, whereas the younger children showed a more diverse learning pattern in the active condition. These findings suggest the presence of early enactment effects that later diminish.

## 8.1 Introduction

Embodied accounts of language consider language to be an integrative part of the sensory-motor representations of actions (Barsalou, 2008). Although there is strong evidence for an interrelation of action and language in adults (see Fischer & Zwaan, 2008 for a review) only a few studies investigated the development of this common representation. Evidence for a of a general interrelation of language and action in development has been reported primarily from longitudinal studies that compared action skills at a preverbal age with linguistic skills at a later age: The increase of rhythmic arm gestures is related to the beginning of reduplicated babbling (Thelen, 1979) whereas the first productive words are influenced by developmental skills such as in object displacement (Lifter & Bloom, 1989) and recognitory gestures . Names of objects that are easy to manipulate enter the productive vocabulary repertoire first (Nelson, 1973; Rodgon, Jankowski, & Alenskas, 1977) and finally, communicative pointing and the ability of joint attention have shown to be precursors to linguistic abilities (Bates, Benigni, Bretherton, Camaioni, & Volterra, 1979; Carpenter, Nagell, & Tomasello, 1998). Taken these studies together, they suggest that the early production of actions and communicative gestures is related to later language production abilities.

Given the fact that nonverbal action skills at a preverbal age are bound to a general level of language acquisition at a later age, it is still an open question how this relationship develops at the point in time when children start speaking their first words. One way to investigate this relationship is to explore whether and how action production specifically supports word learning in the context of action verbs, that is to look at verb learning. Verb learning is one of the fundamental steps in language acquisition. Children make use of a variety of contextual information in order to learn novel verb labels such as social-pragmatic cues (Bruner, 1983; Nelson, 1973; Michael Tomasello & Barton, 1994), syntactical information (Gleitman, 1990; Landau & Gleitman, 1988) or prosodic cues (Grassmann & Tomasello, 2007, 2010). However, it is not known yet whether the production of a newly introduced action is actually beneficial or even necessary in order to learn the corresponding action label. It is an unanswered question whether such an embodied representation of an action has an influence on the learning of the semantic meaning of this verb during language acquisition?

Evidence on a supportive function of action production on word learning in adults comes from the research on enactment. The main findings of this research suggest that the retrieval of verb labels is facilitated when they are learned trough the bodily enactment of the verb. This research started in the 1980s (Cohen, 1981; Engelkamp & Krumnacker, 1980; Saltz & Donnenwerth-Nolan, 1981) and was recently extended to foreign language acquisition (Kelly, McDevitt, & Esch, 2009; Macedonia & Knösche, 2011; Tellier, 2008). Macedonia and Knösche (2011), for example, showed that the recall of newly learned item in an artificial language is enhanced by learning it through enacted gestures in adults.

The present study was designed to investigate the extent to which children between 2 and 3 years of age would benefit from enactment in verb learning. We used a verb-learning paradigm to explore the differences between children who learned a novel action word in combination of the production of the respective action (*active condition*) and children who learned a novel action word but only observed another person producing the respective actions (*passive condition*). After a training phase children were asked to produce the action that corresponded to the newly acquired verb on test objects. In both conditions the complexity of the actions was manipulated, and the children administered two different actions types: In the *object action,* a means object was brought to an end object. The corresponding motion was straight and similar in all actions. The complexity of the object action was low and we expected children to primarily focus on the objects (Behrend, 1990; Forbes & Farrar, 1995; Kersten & Smith, 2002). Accordingly, we hypothesized that the production of the action in the active condition would not enrich the linguistic representation as the action were defined in terms of their object couplings. In contrast, in the *motion action* a small wooden pellet (means object) was transported via different mechanisms. Here, the means object was the same in all actions but the action differed with respect to the end object and to the motion of the respective action. The motion action was more complex compared to the object condition. In this motion action type we expected children to more strongly focus on the motion information. We hypothesized that the linguistic representation should be enriched by own experience of the motion in the *active condition*.

## 8.2 Methods

**Participants**. We tested and analyzed data from 96 children at 24-, 30- and 36-months with 32 children in each age group (24-months: $M = 24.6$, $SD = 0.3$, 16 girls; 30-months: $M = 30.6$, $SD = 0.3$, 16 girls; 36-months: $M = 24.6$, $SD = 0.3$, 16 girls). 7 additional children were tested but excluded from the final analysis due to lack of attention ($n = 5$; active condition $n = 2$, passive condition: $n = 3$) or experimenter failure ($n = 2$). Infants were recruited from a database of parents who had volunteered to participate in child development studies in a mid-sized German city. The children were all monolingual native German speakers and came from heterogeneous socioeconomic backgrounds. They received a present at the end of the session.

**Stimuli**. Infants were presented with three different actions in each of the two action types (object action, motion actions). One of these actions served as target action and was labeled while the other two served as distractor actions.

*Object Actions.* In the object action type, a means object was moved towards an end object. Three pairs of means-end objects were used. The main goal of these actions was to bring the two objects together, but the specific relation (beneath, above, into each other) was varied between the three actions, see Figure 1a. All objects were easily distinguishable by color and shape; they were about the same size (4 x 4 cm) and unfamiliar for all children.

*Motion Actions.* For the motion action condition, we built three novel wooden boxes. These boxes were of different shape and about the same size (20 x 20 x 5 cm). All boxes had a similar functionality: a small wooden block could be put on a specific location and then moved to another location by using a handle. The location where the block could be put and the way the handle worked was varied between the three actions (pulling handle, rotating handle, pushing handle), see Figure 1b. For the test phase, a second set of nearly identical boxes was constructed. In contrast to the training phase, these boxes had two handles, one handle that corresponded to the handle of the training box and a second handle that corresponded to one of the other boxes' handle. These were used in order to distinguish between children conceptualizing actions to object appearances and children conceptualizing actions to motion (Kersten & Smith, 2002).

**Design & Procedure**.

*Design.* A between-subjects design was used. Children were randomly assigned to either the active condition or the passive condition. The presentation of the action types was blocked. The order of the action types, the object serving as the target object within each set in a given action type, the position of the target object in each action type sequence (first, middle, last), and the label of the target action (baffen, fieben) were counterbalanced.

*Training*. After a short familiarization and instruction phase in the test room, the experimental session began. During the training session each of the three actions of a given action type was presented for a total of three times. The experimenter and the child sat next to each other at a table (140 x 100 x 80 cm), while the parent sat on a chair about 2 m away behind the table and completed the German version of the MacArthur-Bates Communicative Development Inventories (Fenson et al., 1993), FRAKIS (Szagun, Stumper, & Schramm, 2009). Next to the table where the experimenter and the child sat was a cupboard where all objects were located. From the child's perspective only the objects on the table but not those inside the cupboard were visible. In the training phase only one action at a time was shown on the table. For each action the experimenter took the relevant objects from the cupboard, placed them on the table and demonstrated the respective action to the child. In case of the target action, the experimenter used the following sentences at the very same points in time as in case of the distractor actions: 'Ich zeig dir [verb].' (I'm going to show you [verb]). 'Schau mal, so geht [verb].' (Look, this is how [verb] works.) 'Jetzt habe ich [past tense of verb].' (Now, I [past tense of verb].) In case of the two (unlabeled) distractor actions, the experimenter said before getting the objects from the cabinet: 'Ich zeige dir was.' (I'm going to show you something.) After putting the objects on the table, she said: 'Schau mal, so geht das.' (Look, this is how it works.') and after modeling she said: 'Jetzt habe ich das gemacht.' (Now, I did that.) After this demonstration the procedure differed for the two conditions. In the *active condition* the experimenter said: 'Jetzt kannst du das machen / Jetzt kannst du [verb].' (Now, you can do it / Now, you can [verb].) and subsequently moved the objects to the front part of the table in order to have the child imitate the action. If the child was not able to imitate the action, the experimenter assisted (the imitation proficiency was coded). In the *passive condition* the experimenter said: 'Jetzt kann ich das nochmal machen / Jetzt kann ich nochmal [verb].' (Now I can do it again/ Now I can [verb] again.) and subsequently modeled the action one other time. Please note, that the experimenter did not move the objects in this condition, they remained at the same location.

This way, the experimenter presented one sequence of all three actions to the child in a predefined order. This procedure was repeated twice. In between each of the three sequences, she said, 'Jetzt machen wir das nochmal.' (Let's do this again.). As a result, each of the three actions of a action type was presented three times resulting in a total of 9 action sequences; and the experimenter labeled the respective target action for a total of twelve times.

*Test.* The test phase followed immediately after the training phase and did not differ between the conditions. The experimenter said: 'Jetzt hole ich nochmal alles zusammen raus.' (Now, I'll get you all together) and arranged the test action objects together on a panel in a random order inside the cupboard. While she did that, she said: 'Du zeigst mir [verb]. Ich hole alles raus und du zeigst mir [verb].' (You'll show me [verb]). I'll get you all together and you'll show me [verb]. While putting the panel on the table, the experimenter said: 'Zeig mir mal [verb].' (Show me [verb].) Note that the experimenter never looked at the objects but only at the child while saying this. The experimenter repeated her request if needed until the child chose one object/box and performed an action on it.

**Coding and reliability.** The children's responses were coded from videotape. In order to see whether children had learned the verb label, for each trial we coded whether children chose the target object in response to the experimenter's request (*object choice*) and whether children performed the target action (*motion choice*). This was coded for both action types. The target object was the one that was used with the target label in the training phase. The target motion could either be performed on the target object or on the distractor object with the same handle. From these two choice categories we further calculated a scale variable combining the two choices mutually (*learning pattern*): motion + object correct, only motion correct, only object correct, neither correct.

In addition, we coded the *imitation proficiency* of the children in the *active condition* for each action type separately. We coded '3' for no help necessary, '2' for location help necessary, '1' for motion help necessary and '0' for location and motion help necessary. Location help refers to help where the objects come together in the simple actions and where the wooden block has to be placed in the complex action. Motion help refers to the actual movement in the simple action and to the usage of the handle in the complex action. The imitation proficiency was coded for the two distractor actions and the target action during the three presentations of each action separately. In sum, nine actions were coded for each action type, and the two average imitation scores were calculated for each child.

To assess interrater reliability, a random sample of 25% of the trials was independently coded by a research assistant who was unaware of the respective condition. She coded which object/box children chose at test and which motion was performed, she was unaware of which object the target was. The reliability of the imitation proficiency was assessed as well. As a measure of agreement, Cohen's kappa was calculated for the categorical rating (children's object + motion choice) and Cohen's weighted kappa (Fleiss & Cohen, 1973) was calculated for the rating using an ordinal scale. This resulted in the following values indicating a high interrater agreement: $\kappa = .96$ for object choice, $\kappa = .95$ for motion choice and $\kappa = .85$ for imitation proficiency.

## 8.3 Results

Preliminary analyses revealed no effects of gender, trial order, or target action. Analyses were thus collapsed over these factors. For each action type and age group three analyses were carried out: the first analysis (I) tested whether children chose the target motion above chance as a measure of verb learning, the second analysis (II) compared the learning patterns between the two conditions in order to look at differences between the mere observation of an action and the own production of the respective action with respect to the learning of the action verb. The third analysis (III) investigated the imitation proficiency of the children in the active condition as a measure of the action competence at the age groups. See Figure 2 for an overview of the results.

**Object Actions.** (I) The object action labels were learned above chance by all three age groups in both conditions as indicated by binomial tests of *target action* performed against chance (.33), 24-month-olds: active condition: $p$ = .004; passive condition: $p$ = .015; 30-month-olds: active condition: $p$ = .015; passive condition: $p$ < .001; 36-month-olds: active condition: $p$ = .004; passive condition: $p$ = .015. (II) The *learning pattern* was not different between the conditions as tested with Chi-Square tests in the different age groups, all $p$s > .209. (III) With respect to the *imitation proficiency,* all three age groups did imitate the actions without help as indicated by the descriptive values that are close to ceiling, 24-month-olds: $M$ = 2.86, $SD$ = 0.17; 30-month-olds: $M$ = 2.97, $SD$ = 0.08; 36-month-olds: $M$ = 2.96, $SD$ = 0.16.

**Motion Actions**. (I) The motion action labels were learned above chance by the 36-month-olds in both the active ($p$ = .004) and the passive ($p$ < .001) condition. The 30-month-olds only learned the novel verb in the active condition, $p$ = .015, but not in the passive condition, $p$ = .18. The novel verb was not yet learned by the group of 24-month-olds in neither condition, all $p$s > .33. (II) We compared the *learning pattern* of the motion action between the active and the passive condition with a chi-square test. While in the active condition, the 24- and 30-month-old children learned at least a correct part of the verbal concept (only motion or only object correct), the children in the passive condition were either completely correct (object + motion object) or completely incorrect, 24-month-olds: $\chi 2(3, N = 32) = 7.94$, $p = .047$, $\Phi = .50$; 30-month-olds: $\chi 2(3, N = 32) = 8.54$, $p = .036$, $\Phi = .52$. At the age of 36 months children did not differ any more in terms of their learning pattern, $\chi 2(3, N = 32) = .73$, $p = .87$, $\Phi = .15$. (III) Finally, we analyzed the *imitation proficiency* of the three age groups. Only the 30- and 36-month-old children did imitate the actions mainly without help as indicated by the descriptive values, 24-month-olds: $M$ = 1.97, $SD$ = 0.62; 30-month-olds: $M$ = 2.68, $SD$ = 0.21; 36-month-olds: $M$ = 2.91, $SD$ = 0.12. We further conducted Mann-Whitney U-tests to compare the different age groups and found that 24-month-olds were less proficient at imitating than the 30-month-olds; $U$ = 28.5, $p$ < .001, $r$ = .98 and than the 36-month-olds; $U$ = 40.5, $p$ < .001, $r$ = .82, while the two older age groups did not differ with respect to their imitation proficiency, $U$ = 92.0, $p$ = .28, $r$ = .40.

## 8.4 Discussion

In order to investigate the influence of enactment on verb learning, we investigated the verb-learning pattern in 2- to 3-year old children in an active condition where children observed and imitated a set of presented actions and in a passive condition where children only observed the same set of actions. We compared the verb learning ability between the active and the passive condition and found different patterns for the object and the motion action.

**Object actions.** The results of the object actions replicate previous findings on verb learning skills at 24 months of age. Two-year old children have previously been shown to learn novel labels in non-ostensive and overhearing contexts (Akhtar, Jipson, & Callanan, 2001; Michael Tomasello & Barton, 1994) and even for absent actions (Akhtar & Tomasello, 1996). Here the reproduction of the action labeled was manipulated and we show that from 2 years of age children learned the novel label in both conditions equally well. In line with previous findings that showed a strong focus on object appearances (Behrend, 1990; Forbes & Farrar, 1995; Kersten & Smith, 2002) we found no enhanced verb learning in the active compared to the passive condition. Kersten and Smith (2002) showed that 3.5- to 4-year-old children learned verbs in the presence of objects that involved certain motion paths to another object. The children were then asked whether the test events that changed in object or motion path would still be examples of the newly learned verbs. Kersten and Smith analyzed their data in terms of whether children believed the test event to belong to the same category in the four conditions (object + action match, object match, action match, no match) and found that children attended equally to the appearances of objects and their motion. In the present study, the object actions were similar to the actions used in the study of Kersten and Smith (2002). In this action type, children were required to focus their attention more on the objects involved and less on the motion required. Therefore, in the active condition, the children did not benefit from the additional information acquired through the enactment of the action, as this information was not relevant for matching the label to the action.

**Motion Actions**. In contrast to the object actions, in the motion actions, the embodied representation of the action formed via the own production of the respective action was beneficial for learning the label of a motion action at the age of 24 and 30 months. Later in development, at the age of 36 months, this advantage disappeared. This finding supports the results on enactment in adults on foreign language acquisition (Kelly et al., 2009; Macedonia & Knösche, 2011; Tellier, 2008) and furthermore extends them on the early development of first language acquisition.

In contrast to the actions used by Kersten and Smith (2002), in the motion actions of our study, motion information was as relevant for the identification of the action. The additional information acquired through the production of the action similarly enriched the visual representation of the action as in the object action type. But in contrast to the object actions, the motion was an essential constraint for the verbal concept. Accordingly, for motion action types, the embodied representation was relevant and beneficial for the acquisition of the corresponding label. In fact, the beneficial effect of enactment was expressed by the acquisition of partly correct semantic concepts (e.g., when either the correct object was chosen or the correct motion was performed) in the younger ages. The results suggest that action production helps to focus on the constraints on what a verb may mean in the context of the involved object (Kersten & Smith, 2002).

Verb learning presupposes an action representation that is then bound to the linguistic representation. This action representation is firstly generated by the observation of somebody performing the action and is subsequently enriched by the own production of the action. In our design action imitation after observation lead to better results compared to pure observation. For this reason the acquisition of a novel label might be facilitated when the novel action is performed and thus enriches the action representation information generated by observation. This additional, embodied form of representation resulted in the 2.5-year-olds succeeding in the active condition of the motion action task but not in the passive condition.

**Action Production.** Action production per se seems to be another beneficial component of verb learning. The children learned the label of the action only when they were able to reproduce the respective action. At the age of 2 years when action production abilities are still limited, children were able to imitate the object actions but not the motion actions. The same differential effect was found in their acquisition of the corresponding label. Two-year-olds did learn the label of the object action in both conditions while they were not successful in learning the label of the motion action in neither condition. It is therefore legitimate to conclude that children acquire the label for an action only if they are able to produce the respective action. This interpretation is supported by the general interrelation between action and language at earlier ages (Capirci et al., 2005; Lifter & Bloom, 1989; Nelson, 1973; Rodgon et al., 1977; Thelen, 1979).

**Development**. Concerning the developmental change in the importance of action production, the question arises what happens between the stage where action production helps and the stage where it is not beneficial any more. Why is action production beneficial at the beginning of verb learning and less after the acquisition of a certain amount of expertise? It is possible that the establishment of an action concept is later inferred from mere observation. This idea is mirrored by the effect of ostensive cues and joint attention as early constraints on word learning (Carpenter et al., 1998; Morales et al., 2000; Parise & Csibra, 2012) that is diminished at later stages where children can learn novel words without ostensive cues (Tomasello & Kruger, 1992) and in overhearing contexts (Floor & Akhtar, 2006; Gampe, Liebal, & Tomasello, 2012). This way, action perception might be as informative as action production at a certain point in development.

**Conclusion.** Taken together, the findings of this study provide evidence for an interrelation between language and action on two levels. Firstly, enactment is beneficial for verb learning of actions that are primarily defined by their motion constraints. Secondly, the ability to reproduce an action seems to be a prerequisite for the learning of the respective action word.

**References**

Akhtar, N., Jipson, J., & Callanan, M. A. (2001). Learning Words through Overhearing. *Child Development*, *72*(2), 416–430. doi:10.1111/1467-8624.00287

Akhtar, N., & Tomasello, M. (1996). Two-year-olds learn words for absent objects and actions. *British Journal of Developmental Psychology*, *14*(1), 79–93. doi:10.1111/j.2044-835X.1996.tb00695.x

Barsalou, L. W. (2008). Grounded cognition. *Annual Review of Psychology* (Vol. 59, pp. 617–645). Palo Alto: Annual Reviews.

Bates, E., Benigni, L., Bretherton, I., Camaioni, L., & Volterra, V. (1979). *The emergence of symbols: Cognition and communication in infancy.* New York: Academic Press.

Behrend, D. (1990). The Development of Verb Concepts - Childrens Use of Verbs to Label Familiar and Novel Events. *Child Development*, *61*(3), 681–696. doi:10.1111/j.1467-8624.1990.tb02811.x

Bruner, J. (1983). *Child's talk: Learning to use language.* New York: Norton.

Capirci, O., Contaldo, A., Caselli, M. C., & Volterra, V. (2005). From action to language through gesture: A longitudinal perspective. *Gesture*, *5*(1-2), 155–177. doi:10.1075/gest.5.1.12cap

Carpenter, M., Nagell, K., & Tomasello, M. (1998). Social cognition, joint attention, and communicative competence form 9 to 15 months of age. *Monographs of the Society for Research in Child Development.*, *63*, V–143.

Cohen, R. (1981). On the Generality of Some Memory Laws. *Scandinavian Journal of Psychology*, *22*(4), 267–281. doi:10.1111/j.1467-9450.1981.tb00402.x

Engelkamp, J., & Krumnacker, H. (1980). The Imaginal and Motor Processes as Performance Recall Influences of Verbal Material. *Zeitschrift Fur Experimentelle Und Angewandte Psychologie*, *27*(4), 511–533.

Fenson, L., Dale, P. S., Reznick, J. S., Thal, D., Bates, E., Hartung, J. P., Pethick, S., et al. (1993). *The MacArthur Communicative Development Inventories: User's Guide and Technical Manual*. Baltimore: Paul H. Brokes Publishing Co.

Fischer, M. H., & Zwaan, R. A. (2008). Embodied language: A review of the role of the motor system in language comprehension. *The Quarterly Journal of Experimental Psychology*, *61*(6), 825–850. doi:10.1080/17470210701623605

Fleiss, J. L., & Cohen, J. (1973). The equivalence of weighted kappa and the intraclass correlation coefficient as measures of reliability. *Educational and Psychological Measurement*, *33*(3), 613–619. doi:10.1177/001316447303300309

Floor, P., & Akhtar, N. (2006). Can 18-month-old infants learn words by listening in on conversations? *Infancy*, *9*(3), 327–339. doi:10.1207/s15327078in0903_4

Forbes, J., & Farrar, M. (1995). Learning to Represent Word Meaning - What Initial Training Events Reveal About Childrens Developing Action Verb Concepts. *Cognitive Development*, *10*(1), 1–20. doi:10.1016/0885-2014(95)90016-0

Gampe, A., Liebal, K., & Tomasello, M. (2012). Eighteen-month-olds learn novel words through overhearing. *First Language*, *32*(3), 385–397. doi:10.1177/0142723711433584

Gleitman, L. (1990). The Structural Sources of Verb Meanings. *Language Acquisition*, *1*(1), 3–55. doi:10.1207/s15327817la0101_2

Grassmann, S., & Tomasello, M. (2007). Two-year-olds use primary sentence accent to learn new words. *Journal of Child Language*, *34*(03), 677–687. doi:10.1017/S0305000907008021

Grassmann, S., & Tomasello, M. (2010). Prosodic stress on a word directs 24-month-olds' attention to a contextually new referent. *Journal of Pragmatics*, *42*(11), 3098–3105. doi:10.1016/j.pragma.2010.04.019

Kelly, S. D., McDevitt, T., & Esch, M. (2009). Brief training with co-speech gesture lends a hand to word learning in a foreign language. *Language and Cognitive Processes*, *24*(2), 313–334. doi:10.1080/01690960802365567

Kersten, A. W., & Smith, L. B. (2002). Attention to novel objects during verb learning. *Child Development*, *73*(1), 93–109. doi:10.1111/1467-8624.00394

Landau, B., & Gleitman, L. R. (1988). *Language and Experience: Evidence from the Blind Child*. Harvard University Press.

Lifter, K., & Bloom, L. (1989). Object knowledge and the emergence of language. *Infant Behavior and Development*, *12*(4), 395–423. doi:10.1016/0163-6383(89)90023-4

Macedonia, M., & Knösche, T. R. (2011). Body in Mind: How Gestures Empower Foreign Language Learning. *Mind, Brain, and Education*, *5*(4), 196–211. doi:10.1111/j.1751-228X.2011.01129.x

Morales, M., Mundy, P., Delgado, C. E. F., Yale, M., Messinger, D., Neal, R., & Schwartz, H. K. (2000). Responding to Joint Attention Across the 6- Through 24-Month Age Period and Early Language Acquisition. *Journal of Applied Developmental Psychology*, *21*(3), 283–298. doi:10.1016/S0193-3973(99)00040-4

Nelson, K. (1973). Structure and Strategy in Learning to Talk. *Monographs of the Society for Research in Child Development*, *149*(1-2), 1–138.

Parise, E., & Csibra, G. (2012). Electrophysiological Evidence for the Understanding of Maternal Speech by 9-Month-Old Infants. *Psychological Science*, *23*(7), 728–733. doi:10.1177/0956797612438734

Rodgon, M. M., Jankowski, W., & Alenskas, L. (1977). A multi-functional approach to single-word usage. *Journal of Child Language*, *4*(01), 23–43. doi:10.1017/S0305000900000465

Saltz, E., & Donnenwerth-Nolan, S. (1981). Does motoric imagery facilitate memory for sentences? A selective interference test. *Journal of Verbal Learning and Verbal Behavior*, *20*(3), 322–332. doi:10.1016/S0022-5371(81)90472-2

Szagun, G., Stumper, B., & Schramm, A. S. (2009). Fragebogen zur frühkindlichen Sprachentwicklung (FRAKIS) und FRAKIS-K (Kurzform). *Frankfurt: Pearson Assessment*.

Tellier, M. (2008). The effect of gestures on second language memorisation by young children. *Gesture*, *8*(2), 219–235. doi:10.1075/gest.8.2.06tel

Thelen, E. (1979). Rhythmical Stereotypies in Normal Human Infants. *Animal Behaviour*, *27*(AUG), 699–715. doi:10.1016/0003-3472(79)90006-X

Tomasello, M., & Kruger, A. (1992). Joint Attention on Actions - Acquiring Verbs in Ostensive and Non-Ostensive Contexts. *Journal of Child Language*, *19*(2), 311–333.

Tomasello, Michael, & Barton, M. E. (1994). Learning words in nonostensive contexts. *Developmental Psychology*, *30*(5), 639–650. doi:10.1037/0012-1649.30.5.639

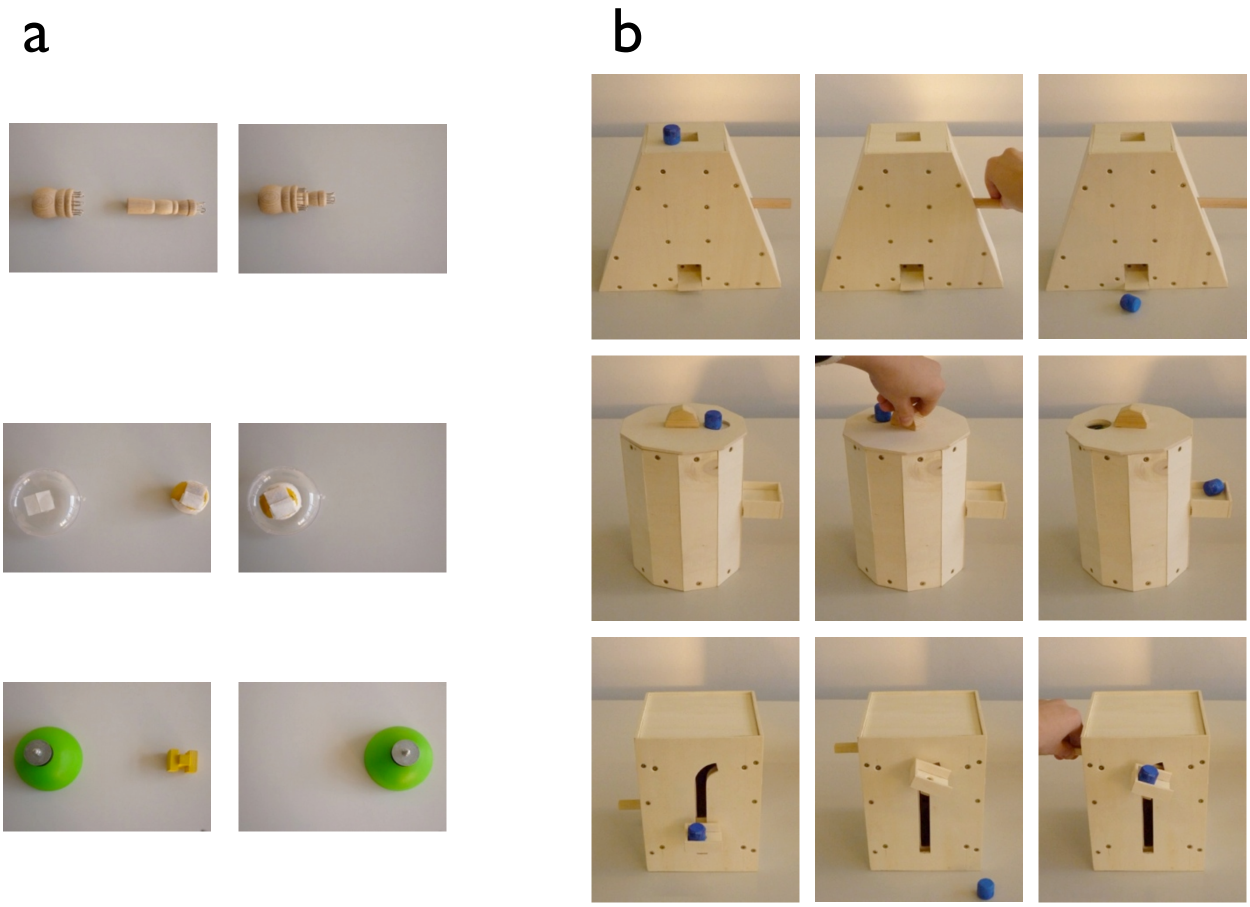


*Figure 1.* Stimulus material used in the present study: a) depicts the object actions with the start state (first) and the end state (second); b) depicts the motion actions with the start state and the location of the wooden block (upper row), the handle use (middle row) and the end state (bottom row).

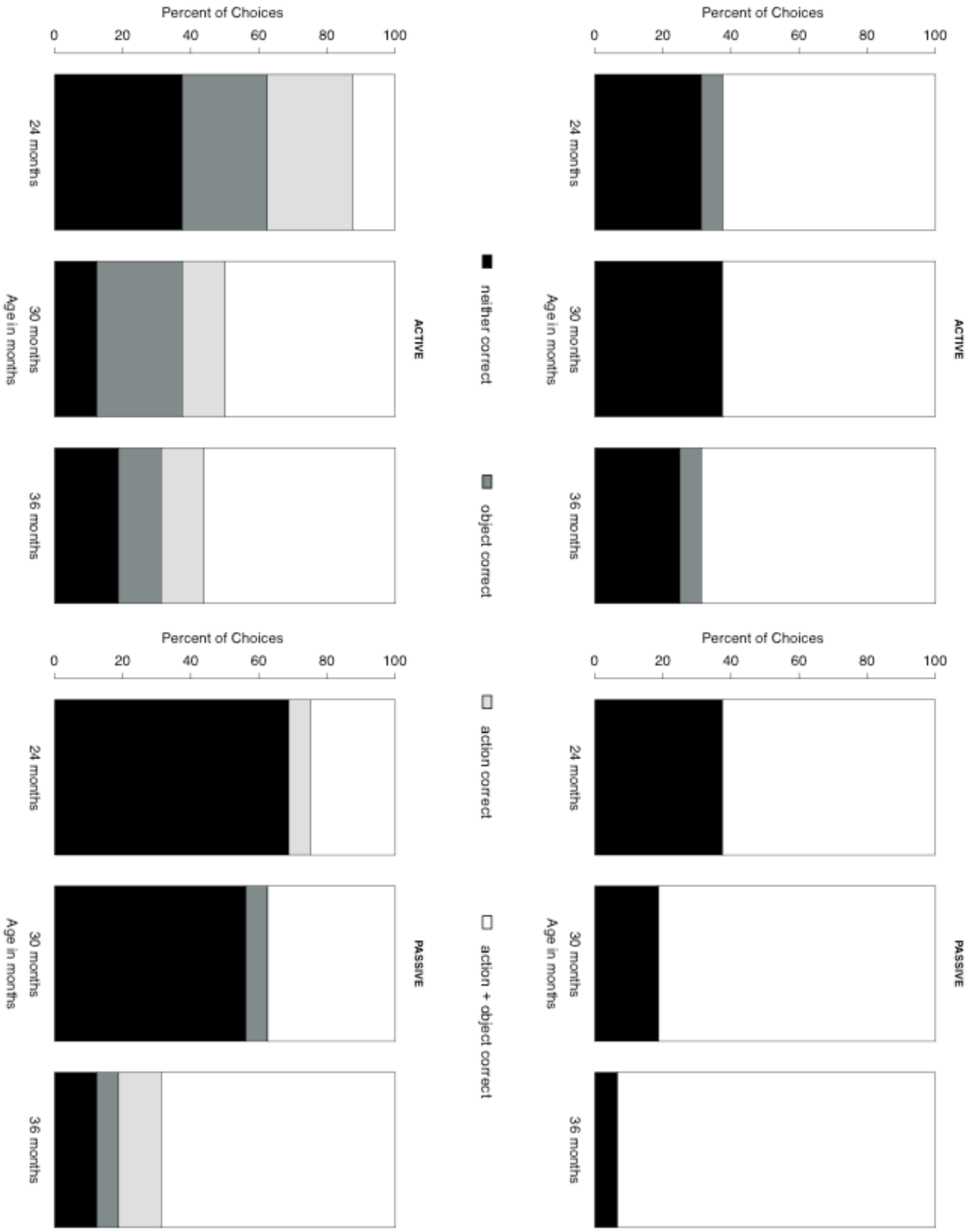


*Figure 2*: The learning pattern in the object actions (above) and the motion actions (below) in the two conditions and the three age groups. While the patterns between the active and passive condition were not different in the object actions, children at the ages of 24 and 30 months acquired more partly correct semantic concepts (only object or only motion correct) in the active condition of the motion actions than in the passive condition.

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